Canada Alberta

FOREST RESOURCE DEVELOPMENT AGREEMENT
ENTENTE SUR LA MISE EN VALEUR DES RESSOURCES FORESTIERES

Canada

Alberta

89-01414/

The Canada-Alberta Forest Resource Development Agreement is a subsidiary agreement of the Canada-Alberta Economic and Regional Development Agreement, which provides coordination and cooperation between the governments of Alberta and Canada in areas of Alberta's economic development.

The Canada-Alberta Forest Resource Development Agreement is funded equally by the governments of Canada and Alberta, from April 1, 1984, to March 31, 1989.

Its primary objectives are to ensure the long-term availability of timber supplies; to optimize timber uses; and to contribute to the growth and diversification of Alberta's economy.

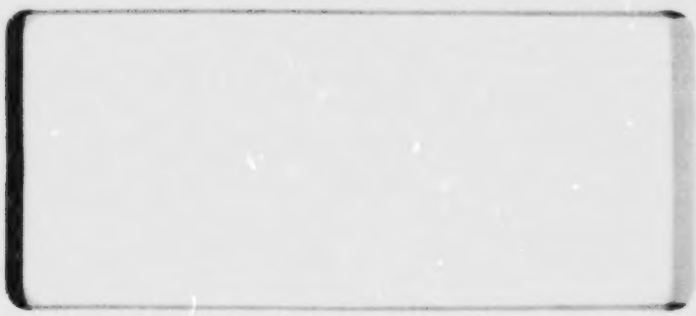
The Agreement comprises three programs: Reforestation; Applied research, technology transfer and opportunity identification; and Public information, evaluation and administration. These programs are managed by a joint Directorate and are implemented by the Canadian Forestry Service and the Alberta Forest Service.

L'Entente Canada-Alberta sur la mise en valeur des ressources forestières est auxiliaire à l'Entente Canada-Alberta sur le développement économique et régional, qui vise à assurer la coordination et la coopération des deux gouvernements relativement au développement économique de l'Alberta.

L'Entente Canada-Alberta sur la mise en valeur des ressources forestières est financée à parts égales par les gouvernements du Canada et de l'Alberta, et a cours du 1er avril 1984 au 31 mars 1989.

Ses objectifs principaux sont assurer la disponibilité à long terme de réserves de bois; optimiser leur utilisation; et contribuer à la croissance et la diversification de l'économie de la province.

L'Entente comprend trois programmes: Reboisement; Recherche appliquée, transferts de connaissances techniques et relevé des occasions; et Information, évaluation et administration. Ces programmes sont gérés par un Bureau de direction conjoint, et mis en oeuvre par le Service canadien des forêts et le Service forestier de l'Alberta.



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VARIABILITY OF MSR LUMBER IN TENSION

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October 1986

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DISCLAIMER

The study on which this report is based was funded under the Canada-Alberta Forest Resource Development Agreement.

The views, conclusions, and recommendations are those of the authors. The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by the Canadian Forestry Service or the Alberta Forest Service.

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ISBN 0-662-15453-3

Catalogue No. Fo 42-91/15 - 1987E

Additional copies of this publication are available at no charge from:

Regional Development
Canadian Forestry Service
5320 - 122 Street
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ABSTRACT

2100f-1.8E Machine Stress-Rated (MSR) lumber is used by Jager Industries Inc. for flanges on their Wood I-beams. As part of the production process, all 2100f-1.8E fingerjoined flanges are tension proofloaded to 1.8 times the design load. Even at this load, however, 1% of the flanges continue to be breaking at locations othern than the joint. This suggests that the tensile strength of the 2100f-1.8E lumber is not being met.

Four visual grading rules to ensure the specified 5th percentile tension parallel-to-grain strength of 2100f-1.8E 2x4 Machine Stress-Rated lumber have been established from the destructive testing of 1073 pieces in 16 foot lengths. These new rules used in conjunction with the National Lumber Grading Authority (NLGA) SPS-2-82 visual requirement reduced the fraction of the sample failing below the specified 5th percentile load because of knots from 11.7 percent to 5.5 percent.

The four new visual grading rules are as follows:

1) For a knot appearing entirely on the wide faces (class 3), and wholly or partially within the outer third of the board width, reject if the knot is greater than 1/5 of the wide face.

2) For a knot emerging at one corner and the opposite wide face (class 8), reject if the knot diameter is greater than 2/3 inch.

3) For a knot emerging at a narrow face and a wide face (class 9), reject if knot displacement (= knot length * average knot diameter) is greater than 15% of the specified cross section area.

4) Reject if the total knot displacement at a cross section is more than 33% of the specified cross section area (class 10).

The study found that use of the NLGA visual requirements alone will reduce the number of pieces in the sample below the specified 5th percentile from 11.7 percent to 8.3 percent.

The first phase of the study indicated that the visual grading process is, on the average, only capable of finding the strength controlling defect in 27 percent of the ongrade pieces but is successful in 59 percent of the off grade pieces. As a result, the efficiency of the new visual overrides when applied to other samples cannot be accurately estimated as yet.

ACKNOWLEDGEMENT

The author thanks Mr. Brian Hintz and Mr. Curtis Miller of Jager Industries Inc., Mr. Clayton Anderson of Alberta Forest Products Association, Dr. Lars Bach of Alberta Research Council, Dr. Friend Bechtel of Metriguard and Mr. Roy Abbott of Forintek Canada Corp. for their efforts which made this project a success.

TABLE OF CONTENTS

Abstract
Acknowledgements

1. INTRODUCTION

2. PARTICIPANTS

3. BACKGROUND ON MSR LUMBER

   3.1 Machine Stress-Rated Lumber
   3.2 Specified 5th Percentile Load

4. MATERIALS

   4.1 Description
   4.2 Sampling
   4.3 Storage

5. METHODS

   5.1 Preliminary Measurements
   5.2 Bending E-rating
   5.3 Tension Testing Machine
   5.4 Tension E-rating
   5.5 Tension Strength Testing
   5.6 Forintek Failure Coding
   5.7 Establishing Visual Overrides

6. RESULTS

   6.1 Preliminary Measurements
   6.2 Bending E-Rating
   6.3 Tension E-Rating
   6.4 Tension Strength Testing
   6.5 Failure Coding
   6.6 Matching of Worst Defect with Failure Defect
   6.7 Visual Overrides

      6.7.1 Phase I
      6.7.2 Phase II

   6.8 Other Causes of Failure
   6.9 Results by Mill

7. DISCUSSION

7.1 Effect of Rate of Loading
7.2 Application of Visual Overrides

8. CONCLUSIONS

9. RECOMMENDATIONS

References

Appendix A - Proposed Procedure
Appendix B - Summary: Equipment Calibration for Jager Study of MSR Lumber
Appendix C - Forintek Knot and Failure Code
Appendix D - Results of Analysis of Failures Due to Knots
Appendix E - Results of Analysis of Failures Due to Slope of Grain and Grain Deviation

LIST OF FIGURES

Figure 1 Third Point Edgewise Bending Tester

Figure 2 Metriguard Model 412B/30 Tension Tester

Figure 3 Strainsert Portable Transducer Indicator and Tension Link Used to Calibrate Tension Tester

Figure 4 LVDT End of Extensiometer Used in Tension Test

Figure 5 Edgewise Bending MOE Distributions for all material as received

Figure 6 Tension MOE Distribution for all material as received

Figure 7 Edgewise Bending MOE vs Tension MOE for all material as received

Figure 8 Ultimate Tensile Load Distribution for material from all four mills

Figure 9 Edgewise Bending MOE vs Ultimate Tensile Load for all material as received

Figure 10 Ultimate Tensile Load Distributions for Class 1 Knot Type Failures

Figure 11 Ultimate Tensile Load Distributions for Class 2 Knot Type Failures

Figure 12 Ultimate Tensile Load Distributions for Class 3 Knot Type Failures

Figure 13 Ultimate Tensile Load Distributions for Class 4 Knot Type Failures

Figure 14 Ultimate Tensile Load Distributions for Class 8 Knot Type Failures

Figure 15 Ultimate Tensile Load Distributions for Class 9 Knot Type Failures

Figure 16 Ultimate Tensile Load Distributions for Class 10 Knot Type Failures

LIST OF FIGURES continued

Figure 17a Well defined class 10 knot (small knots) with pith present, but difficult to measure.

Figure 17b Well defined class 10 knot (large knots) with pith present, but difficult to measure.

Figure 17c Poorly defined class 10 knot with pith present.

Figure 17d Well defined class 2 (edge) knot

Figure 17e Poorly defined class 3 (wide face) knot

Figure 17f Poorly defined class 3 (wide face) knot

Figure 17g Two well defined class 8 knots in the same cross-section

Figure 17h One well defined and one poorly defined class 8 knots in the same cross-section

Figure D-1 Class 1 Knot

Figure D-2 Class 2 Knot

Figure D-3 Class 3 Knot

Figure D-4 Class 4 Knot

Figure D-5 Class 8 Knot

Figure D-6 Class 9 knot

LIST OF TABLES

Table 1	Uncorrected and Corrected Moisture Meter Reading
Table 2	Cross Section Dimensions
Table 3	Apparent Mean Edgewise Bending Modulus of Elasticity
Table 4	5th Percentile Apparent Edgewise Bending Modulus of Elasticity
Table 5	Apparent Mean Tension Modulus of Elasticity
Table 6	5th Percentile Apparent Tension Modulus of Elasticity
Table 7	Ultimate Tensile Load
Table 8	5th Percentile Ultimate Tensile Load
Table 9	Number of Times Worst Defect is Failure Defect
Table 10	Knot Classes Encountered in Phase I
Table 11	Visual Override Rules by Knot Class for 2100f-1.8E MSR Lumber
Table 12	Performance of Visual Override Rules for 2100f-1.8E MSR Lumber
Table 13	Other Failures
Table 14	Results by Mill a) Material as Received b) After Checking Existing NLGA Visual Requirements c) After Checking Existing NLGA and New Visual Requirements
Table 15	Final Results by Mill and Total Above and Below Specified 5th Percentile Tensile Load
Table 16	Percentage of Population Below Specified 5th Percentile Tensile Load
Table C-1	Description of Failures for Dimension Lumber
Table D-1	Class 1 Knot
Table D-2	Class 2 Knot
Table D-3	Class 3 Knot
Table D-4	Class 4 Knot
Table D-5	Class 8 Knot
Table D-6	Class 9 Knot
Table D-7	Class 10 Knot
Table E-1	Slope of Grain (wide face)
Table E-2	Grain Deviation

Forintek Canada Corp., is Canada's wood products research institute providing the Canadian wood products industry and governments with services in research and development and technology transfer.

Forintek's mission is to be the leading force in the technological advancement of the Canadian wood products industry, through the creation and implementation of innovative concepts, processes, products and education programs.

1. INTRODUCTION

Due to the large variability in the mechanical properties of visually graded lumber grades, much of the visually graded lumber is used inefficiently. Through machine grading, Machine Stress-Rated (MSR) lumber can be sorted such that the variability is substantially reduced which results in higher allowable stresses. However, the higher design stresses have meant that much of the MSR lumber is being used in critical applications. These applications include the chords of wood I-beams and trusses where the member is stressed primarily in tension and compression parallel to the grain.

This study is undertaken for Jager Industries Inc. 2100f-1.8E Machine Stress-Rated (MSR) lumber is used by Jager Industries Inc. for flanges on their Wood I-beams. As part of the production process, all 2100f-1.8E fingerjoined flanges are tension proofloaded to 1.8 times the design load. Even at this load, however, 1% of the flanges continue to be breaking at locations other than the joint. This suggests that the tensile strength of the 2100f-1.8E lumber is not being met.

The objective of this study is to determine whether 2100f-1.8E MSR lumber meets the tension requirements of CSA-O86 and, if not, whether the requirements can be met with additional or refined visual overrides. The procedures followed in this study are described in the June 13, 1986 document, "Variability of MSR Lumber in Tension". This document is included in Appendix A. When the procedure actually undertaken differs from that in Appendix A, the alternate procedure and the reasons for adopting the alternate procedure will be discussed.

2. PARTICIPANTS

This study is undertaken for Jager Industries Inc. The four major participants in this study and their contributions are as follows:

Alberta Forest Products Association (AFPA) will assist with all visual grading and ensure the grading is done in conformance with the existing NLGA rules for MSR lumber.

Alberta Research Council (ARC) will review the final report and provide technical input as required.

Forintek Canada Corp. will supervise, perform failure coding, analyze data, develop recommendations for visual override, and become involved as necessary to ensure a scientific approach and write the final report.

Jager Industries Inc. will supply the material, test equipment and perform the testing.

Metriguard Corp. will calibrate all test equipment.

3. BACKGROUND ON MSR LUMBER

3.1 Machine Stress-Rated Lumber

Machine Stress-rating is a grading process where the average stiffness of a piece of lumber is used to predict its strength. Lowpoint apparent MOE may also used, but this is not a requirement. The machine generally used for this purpose in North America is the Continuous Lumber Tester (CLT). Lumber is bend about its weak axis and deflected a fixed amount. The load required to do this is then used to calculate the bending stiffness.

The regulations governing the production of MSR lumber in Canada are contained in the National Lumber Grades Authority (NLGA) Special Products Standard (SPS-2-82). This document and the NLGA Lumber Grading standards form the set of documents outlining the minimum MSR grade requirements.

First, the board is MOE-rated by the CLT and paint sprayed to indicate the stiffness class. The board is then visually inspected for the strength reducing characteristics as specified in Clause A 2.2 and A 2.3 of NLGA SPS-2-82.

Quality control requirements for MSR lumber consists of testing "five pieces of lumber selected from the manufacturing line at some time during each shift, drawn from each lumber size-species combination-grade that is produced during the shift" (NLGA, SPS-2-82). The tests provide data on edgewise bending modulus of rupture and modulus of elasticity for use with quality control charts. Except for a few special MSR lumber grades, there are no quality control requirements directly used to ensure that specified tensile strength levels are met. Quality control for tension strength is not required for 2100f-1.8E lumber.

Allowable stresses for MSR lumber are contained in CAN3-O86-M84: Engineering Design in Wood as well as in SPS-2-82. Tables of allowable stresses contain bending, tension parallel and compression parallel strength values unique to each MSR lumber grade. Shear and compression perpendicular to the grain allowable stresses are taken from tables for visually graded lumber and for the species considered. The allowable stresses as listed in CSA-O86-M84 (Working Stress Design) are as follows:

Extreme fiber stress in bending	= 14.5 MPa (2100 psi)
Tension parallel to grain stress	= 10.8 MPa (1570 psi)
Compression parallel to grain stress	= 11.7 MPa (1700 psi).

The design modulus of elasticity (MOE) is 12400 MPa ($1.8*10^6$ psi).

3.2 Specified 5th Percentile Load

The specified 5th percentile load is the load at or below which 5 percent of the sample will fail. The 5th percentile tensile load is considered here. This load is obtained by multiplying the allowable tensile stress as published in CAN3-O86-M84 for 2100f-1.8E lumber by a 2.1 factor and the cross-sectional area. The 2.1 factor modifies the published value such that the new value represents the short term 5th percentile strength at a unit safety factor. The same factor also applies to the published bending stress.

4. MATERIALS

Four bundles of 2100f-1.8E S-P-F nominal 2 by 4 inch lumber in 16 foot lengths were provided by Jager Industries Inc. at the Wood-I Plant in Calgary, Alberta. Each bundle came from a mill in either British Columbia or Alberta. These mills will be designated Mill A, B, C, and D.

The material was delivered in its original wrapping.

4.1 Description

The material is grade stamped as S-P-F (Spruce-Pine-Fir). Both White spruce and Black spruce were present, but these were only labelled as spruce. Other species were lodgepole pine and White Fir. Species were identified visually as part of the preliminary measurements. The species mix varied with each mill as given in the following table along with the bundle size and province the material came from:

			Species Mix		
Mill	Province	Bundle Size	Spruce	Pine	Fir
A	B.C.	293*	1.7%	95.9%	0.7%
B	Alberta	260	70.8%	29.2%	0.0%
C	Alberta	260	42.7%	53.9%	1.2%
D	B.C.	260	55.8%	43.9%	0.4%

4.2 Sampling

In Phase I, the first 100 pieces removed from the top of a bundle and meeting the existing NLGA visual requirements were selected. Thus four groups of 100 pieces were obtained for Phase I. Visually offgrade material found in selecting material for the first phase was marked offgrade and left in the bundle for testing in the second phase. In the second phase, the remaining material in each bundle was tested. Material from each bundle was marked and kept separate throughout the study.

All material gradestamped as 2100f-1.8E were considered in this study. One piece stamped "Std & Btr" in Mill A's bundle was ignored. A piece stamped as 2100f-1.8 MSR lumber but graded as utility in Mill C's bundle, however, was included.

Pieces sampled in Phase I were numbered sequentially starting with "1" up to "100". Offgrade material found in this selection were numbered from "101". In Phase II, specimens were numbered from "200" onward regardless of whether the piece was on or offgrade. Offgrade pieces were marked and considered in the analysis accordingly.

4.3 Storage

Specimens sampled for Phase I testing were stored in the Wood-I plant at room temperature under dry conditions. The remaining specimens were stored outside and covered with the original wrapping until commencement of Phase II. In both phases, material selected and prepared for testing were kept within the plant.

5. METHODS

5.1 Preliminary Measurements (by AFPA)

After selecting the sample group, each specimen was measured for moisture content, width and thickness. The species was also noted. The preliminary measurements were taken at a defect free section 2 to 3 feet (600 to 900mm) from the end of the board and at the same end of the bundle. Dimension were measured with a caliper to the nearest hundredth of an inch and moisture content was measured using a resistance type moisture meter (Delmhorst)--supplied by AFPA--having probes with 3/8 inch (9.5mm) penetration. For offgrade material, the grade controlling defect was marked on the piece and removed from the first 100 specimen sample but left in the sample for the second phase. In Phase I, the worst defect was also noted for each specimen. This step was taken only for offgrade material in the second phase since sufficient information for ongrade material had been obtained in Phase I.

5.2 Bending E-rating

The bending tester, shown in Figure 1, is one of the quality control equipment in the Wood-I plant and was modified for this study. The tester consists of a frame, loading head, supports, a 3 kip load cell at one support, a hand operated hydraulic pump, and a dial gauge.

A third point loading head was installed and the span was adjusted to 21 times the depth (73.5 inches = 1867mm)). The loading head and end reaction supports were also modified to allow free rotation and horizontal translation.

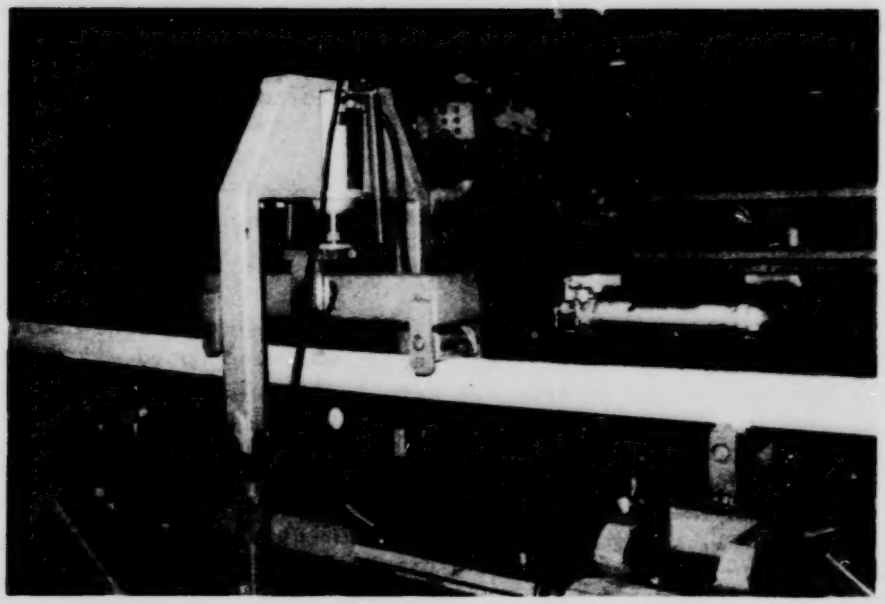


Figure 1. Third Point Edgewise Bending Tester

The bending tester was checked with an aluminum bar with known stiffness (certified by Warnock Hersey, 4/3/85) and was found to be overestimating the bending stiffness by 2%. Just prior to Phase II testing, the bending tester was again checked with the aluminium bar and was still found to be overestimating the stiffness by 2%. As a result, calculated apparent bending MOE (calculated using specified cross section dimension of 1.5 x 3.5 inches or 38 x 89mm) were reduced by 2%. A hysteresis test was also performed to measure the friction in the system. No corrections were made to the measured values to account for friction since the friction component of the force was found to be low. A more complete discussion of machine modifications and the calibration performed prior to Phase I by Metriguard is included in Appendix B.

Measurement of bending modulus of elasticity (BMOE) consisted of centering the specimen longitudinally in the bending machine, applying a total preload of approximately 160 to 200 pounds (or third point load of 80 to 100 pounds), recording the loadcell reading and midspan deflection, increasing the load to between 370 and 420 pounds, and recording the loadcell reading and midspan deflection again (1.0 N = 0.225 pounds). From the four readings and the specimen dimension, a bending modulus of elasticity can be calculated. And since the incremental load and deflection are used, the effects of overhang can be shown to cancel. The preload and final load correspond to flexural stresses of about 640 to 800 psi, and 1480 to 1680 psi respectively (1.0 MPa = 145 psi). This is well below the specified short term 5th percentile flexural strength of 4410 psi (30.4 MPa).

Total elapsed time between preliminary measurements and E-rating was about one day.

5.3 Tension Testing Machine

The tension tests were performed in a Metriguard Model 412B/30 tester, depicted in Figure 2. This tester is normally used to proofload fingerjoints as part of the Wood-I beam production. The tester has a 100,000 pound capacity. Boards oriented on flat (with the wide faces parallel to the floor) are inserted from one end of the machine. The gripping surfaces are lined with a polyurethane.

Actual loading and displacement rates depended on the hydraulic fluid flow. Since the hydraulic flow is initially directed to close the clamps while an axial load is being supplied, the loading cycle is neither strictly load or displacement controlled. However, there is provision to cut hydraulic pressure to the actuators when a load limit is reached. Peak load is displayed on the console.

Figure 2. Metriguard Model 412B/30 Tension Tester

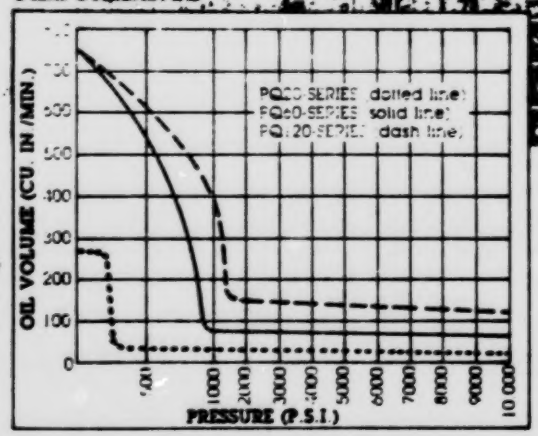
ORDERING INFORMATION

For Use With:	Order No.	Valve Type	Control Function	Reservoir Capacity	Motor
Single Acting Rams	PQ203	3-way	Advance Hold Return	3.3 gal (577 cu. in usable)	¾ h.p 115 volt† or 230 volt (sgl. phase)
	PQ203S	3-way*			
Double Acting Rams	PQ204	4-way			
	PQ204S	4-way*			
Single Acting Rams	PQ603	3-way	Advance Hold Return	5.2 gal (1039 cu. in. usable)	2 h.p 115 volt† or 230 volt† (sgl. phase)
	PQ603S	3-way*			
Double Acting Rams	PQ604	4-way			
	PQ604S	4-way*			
Single Acting Rams	PQ1203	3-way	Advance Hold Return	5.2 gal. (1039 cu. in. usable)	3 h.p 230 or 460† volt (3-phase)
	PQ1203S	3-way*			
Double Acting Rams	PQ1204	4-way			
	PQ1204S	4-way*			

* Solenoid valve with remote control.
† Prewired at factory for this voltage. PQ20 and PQ60 Series available in 230 volt, 50Hz. PQ120 Series available in 220/440 volt, 50 Hz. Consult with factory.

	Max. Amp Draw @ 10,000 p.s.i.	Max. dBA @ 10,000 p.s.i.
PQ20 Series	(115V)—13.4 amps (230V)—6.7 amps	75
PQ60 Series	(115V)—22 amps (230V)—11 amps	76
PQ120 Series	(230V)—10.5 amps (460V)—5.3 amps	78

PERFORMANCE

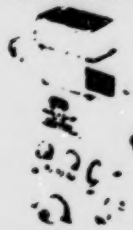


The performance curves at right indicate the oil delivery at various pressure levels for the PQ Series "Quiet" Pumps

unit following an interruption in electrical service. Thermal overload protection is also provided to prevent damage to the motor as a result of overheating. Each will start and operate under full load even if the voltage is reduced by as much as 10%. More detailed information concerning the valving, motor and motor controls can be found on this page with the ordering information.

Valves

Each PQ series pump is equipped with either a manual valve (3-way or 4-way), a solenoid valve (3-way or 4-way), an automatic valve or a manifold and pressure switch. All 3-way and 4-way valves feature "posi-check." The pumps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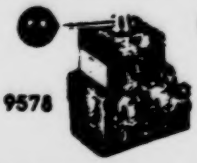
with solenoid valves also have a remote valve control. This is a hand operated control with a spring-loaded switch for advance, hold and return positions.

Manual valves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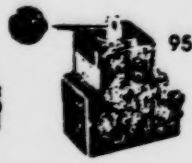
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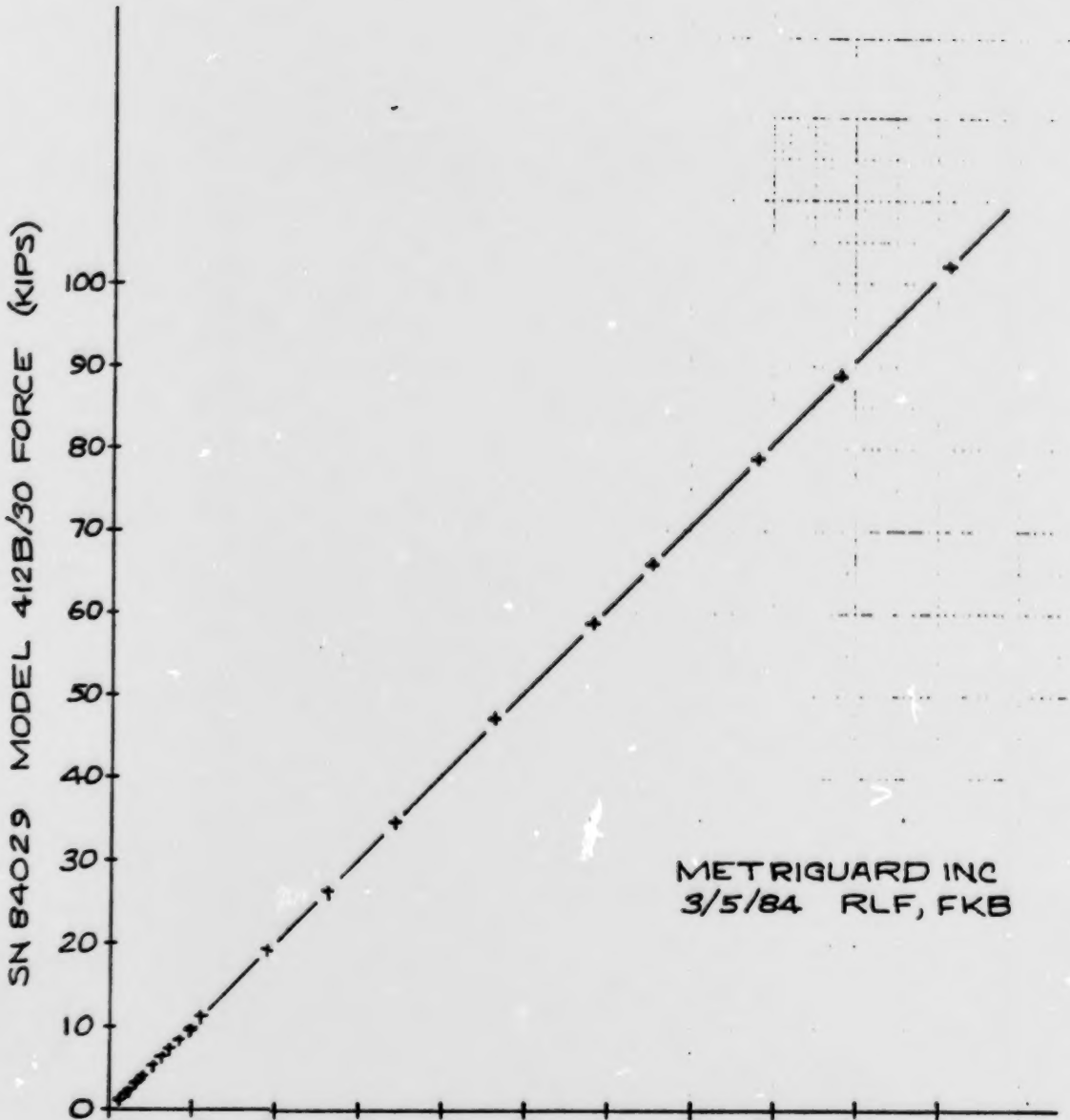
A manual valve is available on any size PQ series pump. A selection of hydraulic pressure gauges is also available to monitor system pressure. For complete information and details on OTC Power Team valves, refer to pages 39 thru 47.

10 gallon reservoirs

For extra oil capacity there are two 10-gallon oil reservoirs for the PQ Series pumps. The pumping unit simply bolts onto the reservoir. For more details, refer to page 52.

See pages 48-53 for hydraulic accessories.

FIGURE 2



TLLR-100-2, DR-1 Q7054-A

CALIBRATION – MODEL 412B/30, SN 84029

FIGURE 4 1

Calibration consisted of inserting a tension link, as shown in Figure 3, and measuring the strain and thus the stress and force in the tension link. The tension machine is calibrated by adjusting the gain until the console reading matches the reading indicated on the Strainsert Model DR portable transducer indicator unit. The tension link is basically a load cell and only ensures that the load displayed on the console is in fact the load being applied

The tension machine was calibrated at the start of Phase I at a load of 17 kips (75.6 KN) and checked prior to beginning Phase II at a load of 26 kips (115.6 KN). These loads correspond approximately to the 5th percentile load and mean failure loads for 2100f-1.8E lumber. A more complete discussion of the initial machine calibration by Metriguard is included in Appendix B.

5.4 Tension E-rating

An extensometer, illustrated in Figure 4, constructed by Metriguard was used to measure the relative displacements of two point on a board. The extensometer consists basically of two clamps, an LVDT, an extension tube, a strain conditioner, and a display for displacements. The signal from the strain conditioner was also fed into the X channel of an HP XY plotter provided by Forintek. The load signal was fed into the Y channel.

First, the specimen is loaded into the machine from the end and centered laterally within the grips with guides. The extensometer then is mounted on the specimen and the tension tester is switched to automatic mode. In this mode, the load on the specimen is increased up to about 10,000 pounds (44.48 KN) and then released automatically. This load was chosen such that a linear load-displacement plot of about 2 to 3 inches (50 to 75mm) in length was plotted. There was an initial nonlinearity in the plot due to variations in the hydraulic pressure as the clamps were applied, the initial sag in the piece due to the piece's self weight, and the plotter's slow reponse.

From the slope of the load displacement-plot, the average tension modulus of elasticity over the 127.5 inch (3.239 m) gauge length can be determined by multiplying the slope of linear portion of the force- displacement plot by a factor equal to the gauge length divided by the cross-section area.

5.5 Tension Strength Testing

When the tension E-rating of the piece has been completed, the extensometer is removed and the tension tester is switched to manual mode. The specimen is then reloaded to failure. Once the specimen has failed, the tester is manually reset. The peak or maximum load achieved during the test is displayed on the console and is recorded on the plot obtained during the tension E-rating by the machine operator. A sudden increase in the load was observed three times just after the specimen failed. This was attributed to the clamps recoiling.

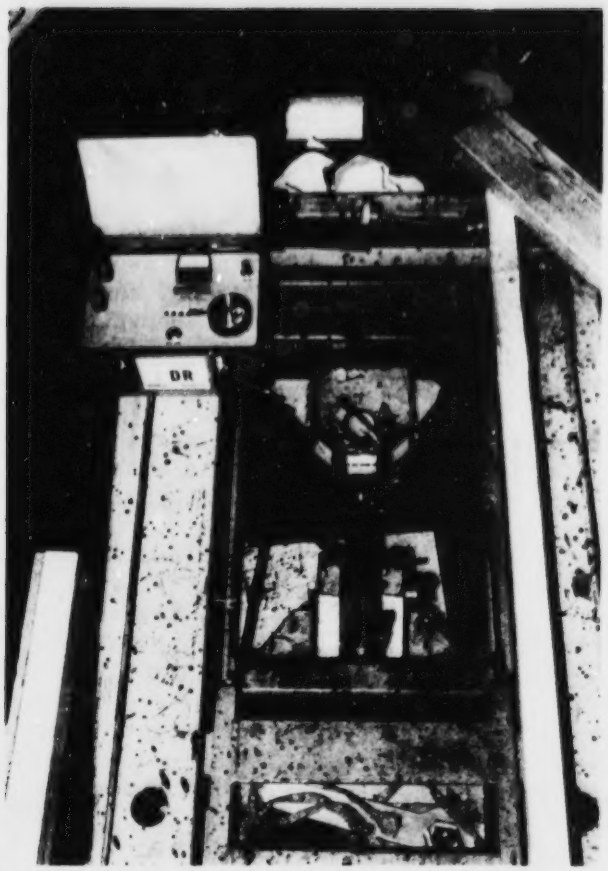


Figure 3. Strainsert Portable Transducer Indicator and Tension Link Used to Calibrate Tension Tester

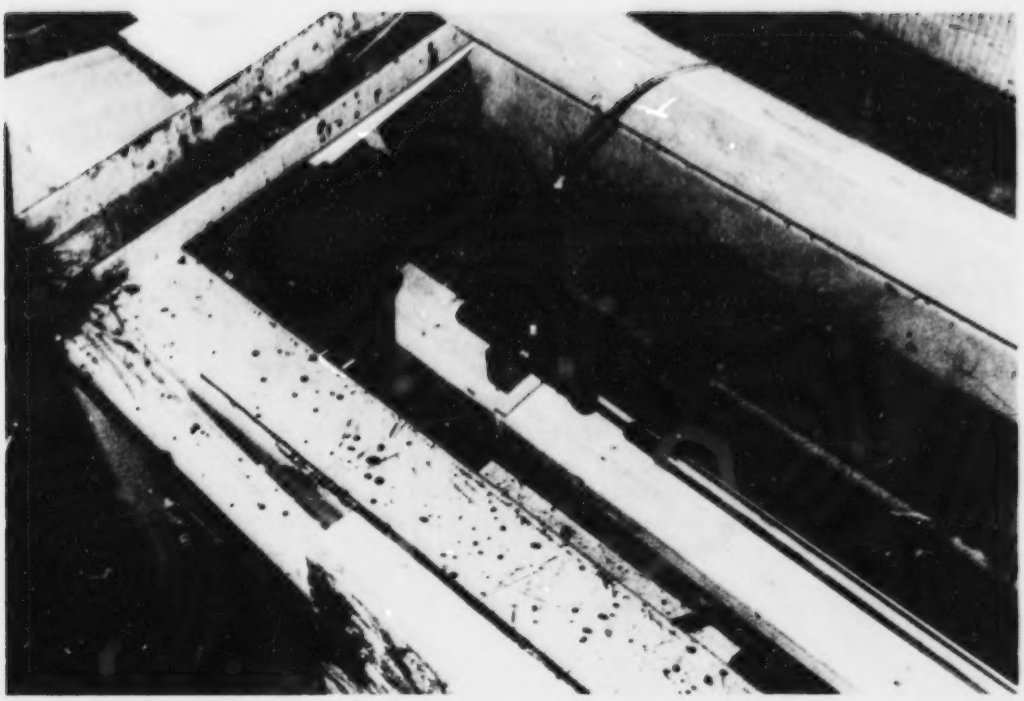


Figure 4. LVDT End of Extensiometer Used in Tension Test

Time to failure was about 10 to 15 seconds. For a mean strength of approximately 5000 psi (34.48 MPa), the stress rate is then about 24,000 psi/minute (165.5 MPa/min). The equipment available could not be adjusted to a lower rate. Although this rate is considerably higher than the rate permitted by NLGA SPS-2-82 (16,000 psi/min) for qualification and quality control testing, the rate was felt to have a negligible effect on the final result and of this study (see for exampled Strickler, 1973). There will be a brief discussion in a later section on the effect of rate of loading.

Total elapsed time between the bending test and the tension test was about one day.

5.6 Forintek Failure Coding

The Forintek failure code is a simple but comprehensive method of describing a failure in lumber. There are ten knot classes which give the dimension of the knot at the failed cross-section. In addition, the method allows one to describe strength reducing defects, such as slope of grain and distorted grain. A more detailed description of the method is given in Appendix C. From the code, a drawing knot of the cross-section can be created. For the purpose of this report, the various knot types will be referred to according to the class as defined by the Forintek Failure Coding.

5.7 Establishing Visual Overrides

The purpose of the visual overrides established in this study is to grade a sample of lumber which meets the NLGA visual requirements but not the specified 5th percentile tensile load requirement. The efficacy of the overrides is dependent on two components: whether the grader is able to find the failure defect amoung a number of defects in an unbroken board; and whether the visual overrides can distinguish between defects causing a board to fail above and defects causing a board to fail below the specified 5th percentile load.

The Forintek failure code was used as a basis for classifying failures. Specimens with the same knot class, for example, will be examined together to establish visual overrides. In addition to the failure coding, the position of the failure from the grade stamped end was also measured to the nearest centimeter. This was used to determine whether the grade controlling defect or the worst defect as perceived by a grader is the defect causing failure. Sufficient information was obtained on how well the grader could determine failure defect in ongrade material in Phase I so this was not done in Phase II. However for offgrade material, worst defect was noted and located in both Phase I and II.

Since the visual overrides were established from descriptions of defects causing failure, the efficacy of the overrides can only be determined from applying these overrides to pieces prior to destructive testing. Thus, visual overrides established at the end of Phase I were applied to the material designated for testing in Phase II.

6. RESULTS

6.1 Preliminary Measurements

The results of the moisture meter readings, dimension measurements, and tension and edgewise bending modulus of elasticity are given in Tables 1 to 3, respectively. Ultimate loads were not corrected for moisture content or under- or oversize material. Instead, results are presented to show that the specimens meet the moisture content requirements for MSR lumber and that the specified cross-section dimensions can be used in the analysis. The results presented in this report reflects how the material would perform when used.

The moisture meter readings were corrected for species effect using a program developed for the Canadian Ingrade study (Hejja, 1985). A moisture content of 19% or less is required for MSR lumber.

TABLE 1 - Uncorrected and Corrected Moisture Meter Reading

	Uncorrected Reading			Corrected Reading		
	Mean (% MC)	CoV (%)	N	Mean (% MC)	CoV (%)	N
Mill A	9.7	19.3	288	12.2	18.3	288
Mill B	13.1	13.2	260	16.5	12.4	260
Mill C	13.2	13.1	258	16.6	12.8	253
Mill D	11.0	13.0	260	13.9	12.3	260
Total	11.7	19.5	1066	14.7	18.8	1061

The distribution of specimen depth and cross-section area are summarized in Table 2. Variations in depth and thickness are errors in manufacturing which affect both the ultimate tensile load and the calculated edgewise bending modulus of elasticity. The mean edgewise bending modulus of elasticity calculated using measure dimensions instead of specified dimensions differed by less than 0.01 (10^6) psi (70 MPa); the coefficient of variation differed by less than 1 percent. Dimensional variations within the board should be less than or equal to dimensional variations between boards.

TABLE 2 - Cross Section Dimensions

	Depth		Thickness		Area		
	Mean (in)	CoV (%)	Mean (in)	CoV (%)	Mean (in)	CoV (%)	N
Mill A	3.51	0.352	1.50	0.601	5.27	0.781	288
Mill B	3.48	0.655	1.51	0.813	5.26	1.262	260
Mill C	3.50	0.616	1.50	0.873	5.25	1.303	259
Mill D	3.50	0.412	1.51	0.753	5.29	0.994	260
Total	3.50	0.567	1.51	0.881	5.27	1.137	1067

6.2 Bending E-rating

The apparent edgewise bending modulus of elasticity should satisfy the NLGA SPS-2 requirements: 5th percentile bending modulus of elasticity ($BMOE_{0.05}$) should be greater than 0.82 times the grade MOE and the mean MOE ($\underline{BMOE}$) should be greater than 0.95 times the grade MOE. Thus for 2100f-1.8E lumber, $BMOE_{0.05}$ should be greater than $1.476(10^6)$ psi (= 0.82 * $1.8(10^6)$) and $\underline{BMOE}$ should be greater than $1.71(10^6)$ psi (= 0.95 * $1.8(10^6)$). Samples from all mills met the $BMOE_{0.05}$ and $\underline{BMOE}$ requirements. Only the bundle from mill B did not meet the $\underline{BMOE}$ requirement. A summary of the $\underline{BMOE}$ and the $BMOE_{0.05}$ is given in Table 3 and 4. Three and two parameter Weibull and normal cumulative proabability plots of edgewise BMOE are given in Figure 5.

TABLE 3 - Apparent Edgewise Bending Modulus of Elasticity

	Ongrade material only			Material as received		
	Mean (10^6 psi)	CoV (%)	N	Mean (10^6 psi)	Cov (%)	N
Mill A	1.85	10.1	270	1.84	10.6	290
Mill B	1.67	8.9	237	1.67	9.0	260
Mill C	1.76	7.8	242	1.75	8.4	260
Mill D	1.79	6.0	233	1.78	6.1	260
Total	1.77	9.2	982	1.76	9.5	1070

NLGA requirement: $\underline{BMOE} \geq 1.71(10^6)$ psi (120 piece sample).

TABLE 4 - 5th Percentile Apparent Edgewise Bending Modulus of Elasticity ($BMOE_{0.05}$)

	Ongrade material only		Material as received	
	5th%ile (10^6 psi)	N	5th%ile (10^6 psi)	N
Mill A	1.57	270	1.56	290
Mill B	1.47	237	1.46	260
Mill C	1.54	242	1.52	260
Mill D	1.62	233	1.61	260
Total	1.53	982	1.51	1070

NLGA requirement: $BMOE_{0.05} \geq 1.476\ (10^6)$ psi (120 piece sample)

Regrading the material to ensure that NLGA visual requirements were met only improved BMOE and $BMOE_{0.05}$ by $0.01(10^6)$ psi or less, for the lumber samples evaluated.

6.3 Tension E-rating

Although there are no requirements for tension modulus of elasticity in NLGA SPS-2, in design, BMOE is used in place of average tension MOE (TMOE). A summary of the apparent tension MOE statistics are shown in Tables 5 and 6. Note that except for Mill B, which remained unchanged, TMOE is consistently lower than BMOE for material as received and for ongrade material. Three- and two-parameter Weibull and normal cumulative probability plots of TMOE are given in Figure 6. A plot of bending MOE vs. tension MOE is given in Figure 7.

TABLE 5 - Apparent Mean Tension Modulus of Elasticity (TMOE)

	Ongrade material only			Material as received		
	Mean (10^6 psi)	CoV (%)	N	Mean (10^6 psi)	Cov (%)	N
Mill A	1.76	11.8	270	1.76	11.7	293
Mill B	1.67	8.1	237	1.67	8.3	260
Mill C	1.71	7.9	242	1.71	8.0	259
Mill D	1.75	5.0	233	1.75	5.1	260
Total	1.73	8.9	982	1.72	9.0	1072

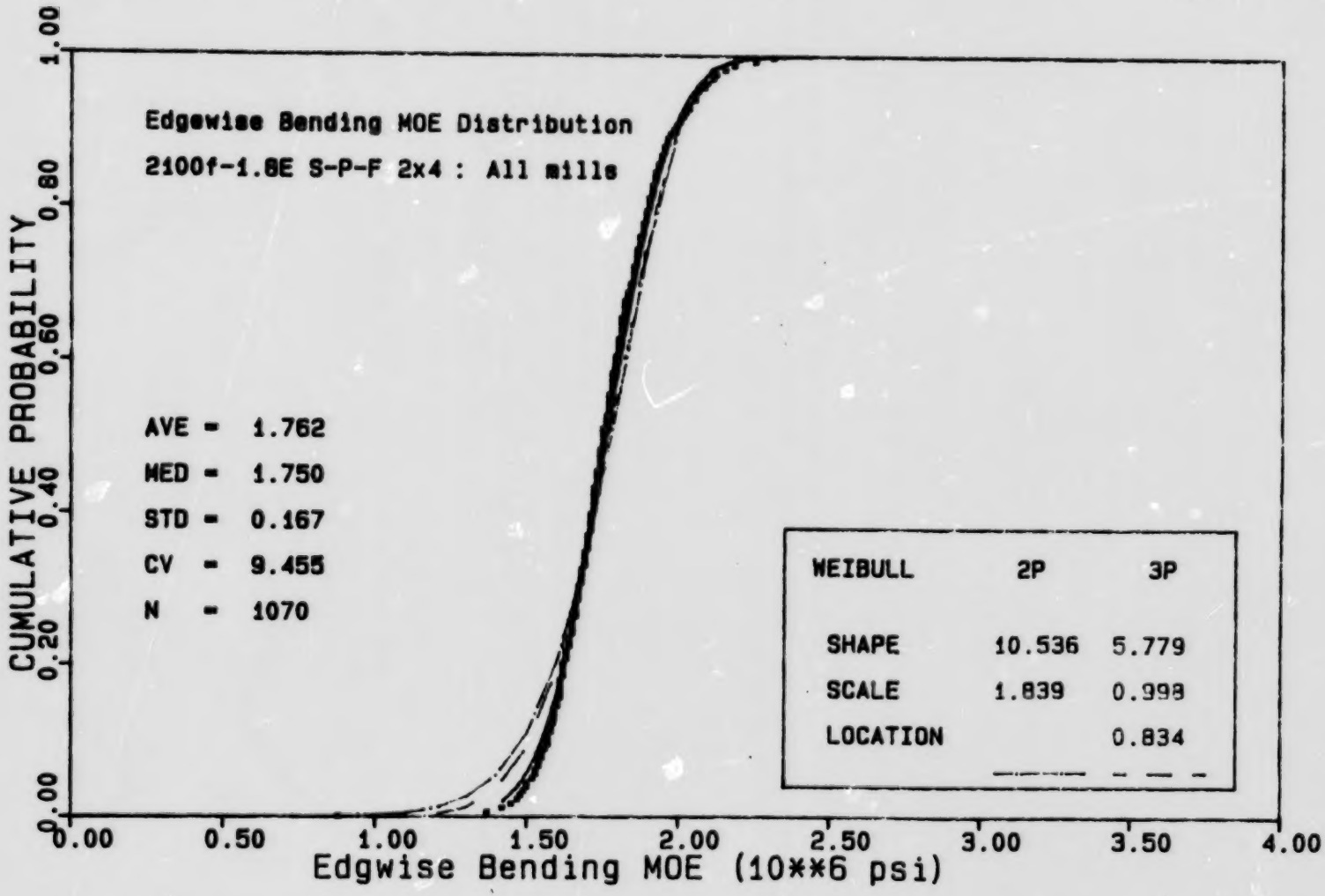


FIGURE 5. Edgewise Bending MOE Distributions for all material as received.

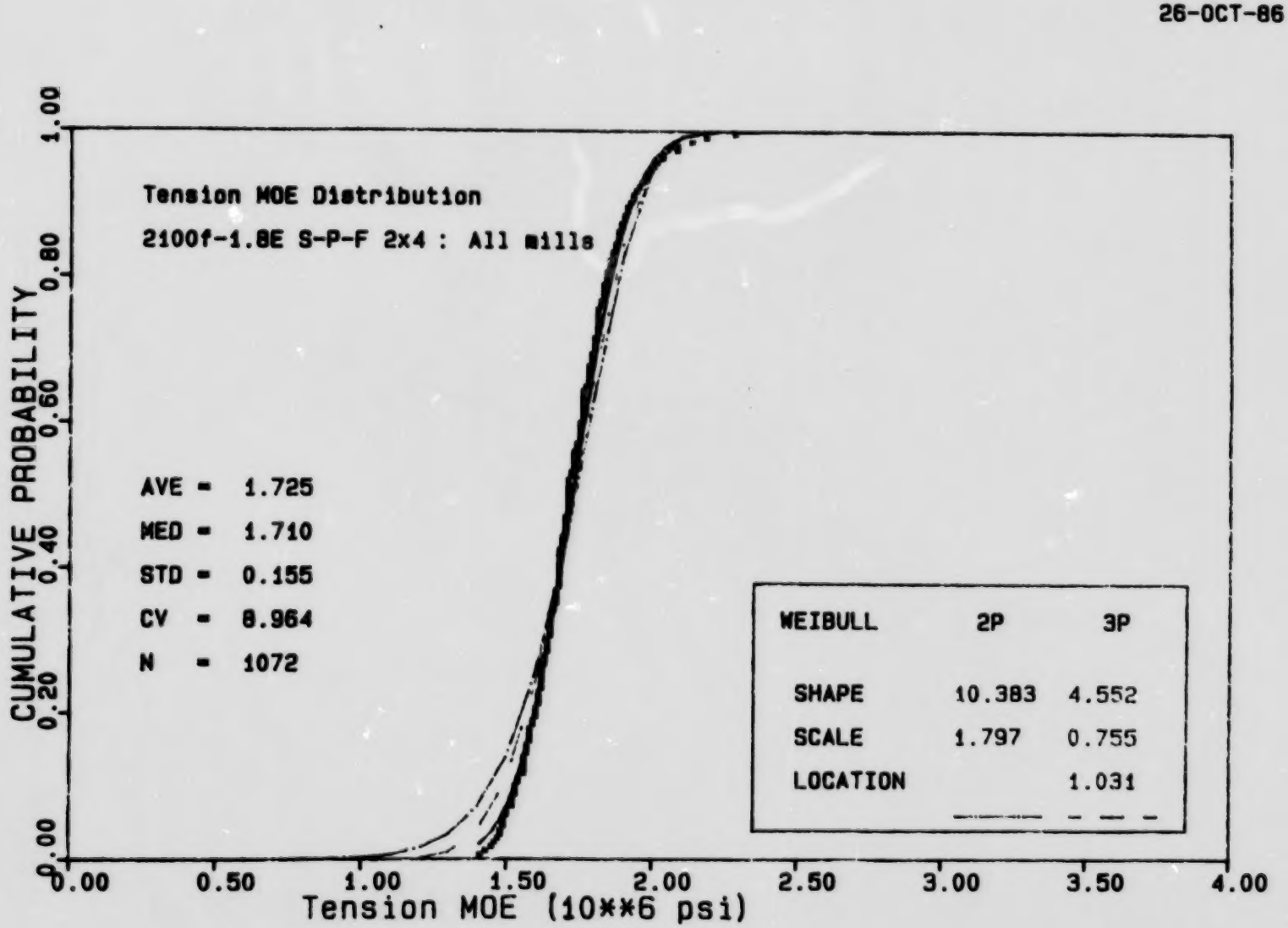


FIGURE 6. Tension MOE Distribution for all material as received.

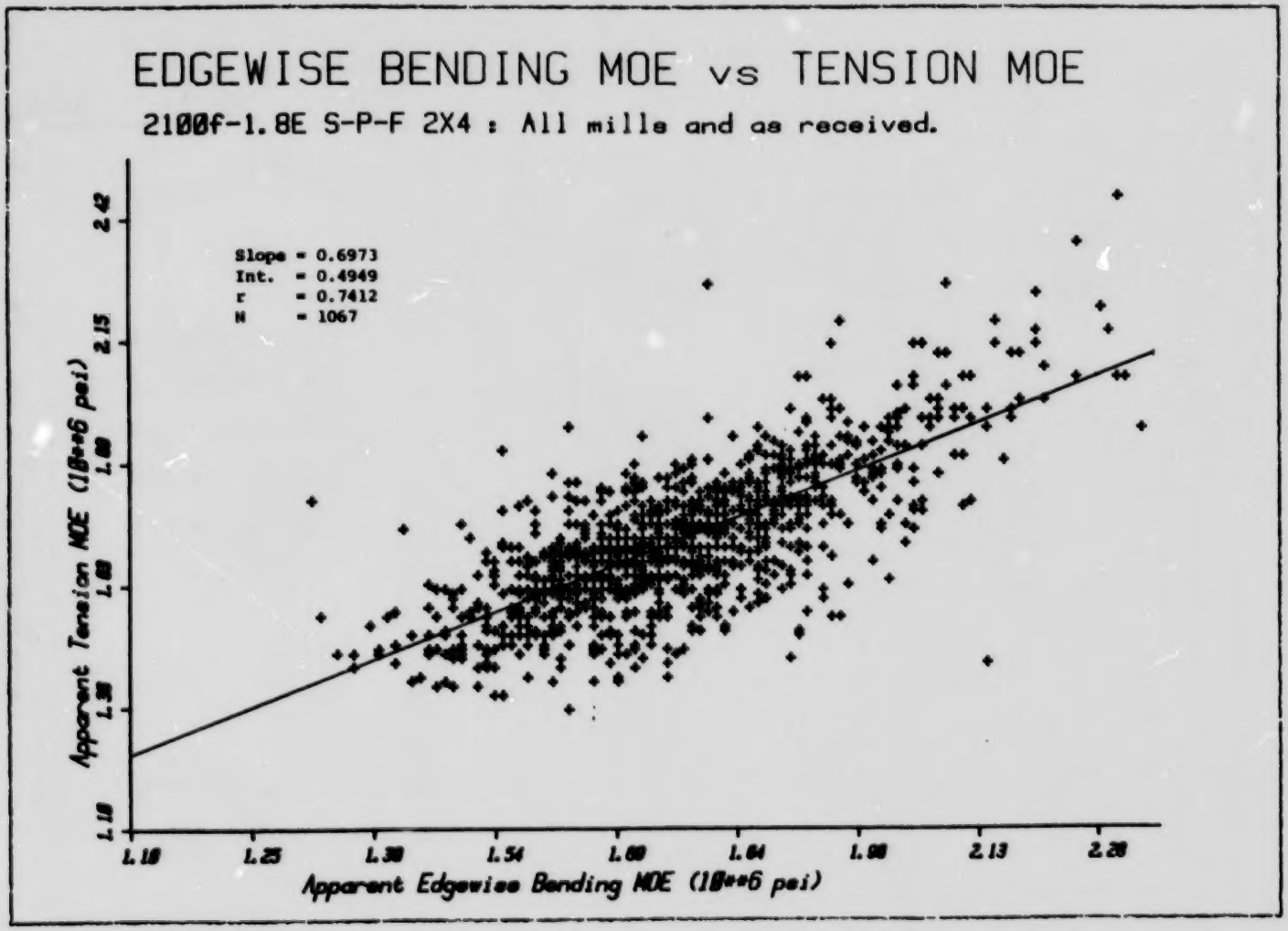


FIGURE 7. Edgewise Bending MOE vs. Tension MOE for All Material as received.

TABLE 6 - 5th Percentile Apparent Tension Modulus of Elasticity ($TMOE_{0.05}$)

	Ongrade material only		Material as received	
	5th%ile (10^6 psi)	N	5th%ile (10^6 psi)	N
Mill A	1.48	270	1.48	293
Mill B	1.48	237	1.48	260
Mill C	1.52	242	1.52	259
Mill D	1.62	233	1.61	260
Total	1.49	982	1.49	1072

Regrading the material to ensure that NLGA visual requirements were met did not improve TMOE or $TMOE_{0.05}$.

6.4 Tension Strength Testing

A summary of tension test results are shown in Tables 7 and 8. Specimens which sliped in the grips are also included. Since these specimens were loaded above the mean failure load, omitting them would have introduced an undesirable bias in the mean. Whether or not the specimen slipped, however, the 5th percentile tensile loads are not affected since all specimens which slipped were loaded or reloaded until a load exceeding 25 kips was achieved. Three- and two-parameter Weibull and normal cumulative probability plots of the ultimate tensile load are given in Figure 8. The correlation coefficient, r, relating edgewise bending MOE and ultimate tensile load is 0.39 (Figure 9). The low r vlaue is due to grading: the variability in MOE has been reduced but not in tensile strength.

TABLE 7 - Ultimate Tensile Load

	Ongrade material only			Material as received		
	Mean (kips)	CoV (%)	N	Mean (kips)	Cov (%)	N
Mill A	24.0	28.4	270	23.6	29.0	293
Mill B	25.3	23.8	237	24.9	25.1	260
Mill C	29.0	21.1	242	28.6	22.5	260
Mill D	28.9	23.9	233	28.0	25.9	260
Total	26.7	25.7	982	26.2	26.8	1073

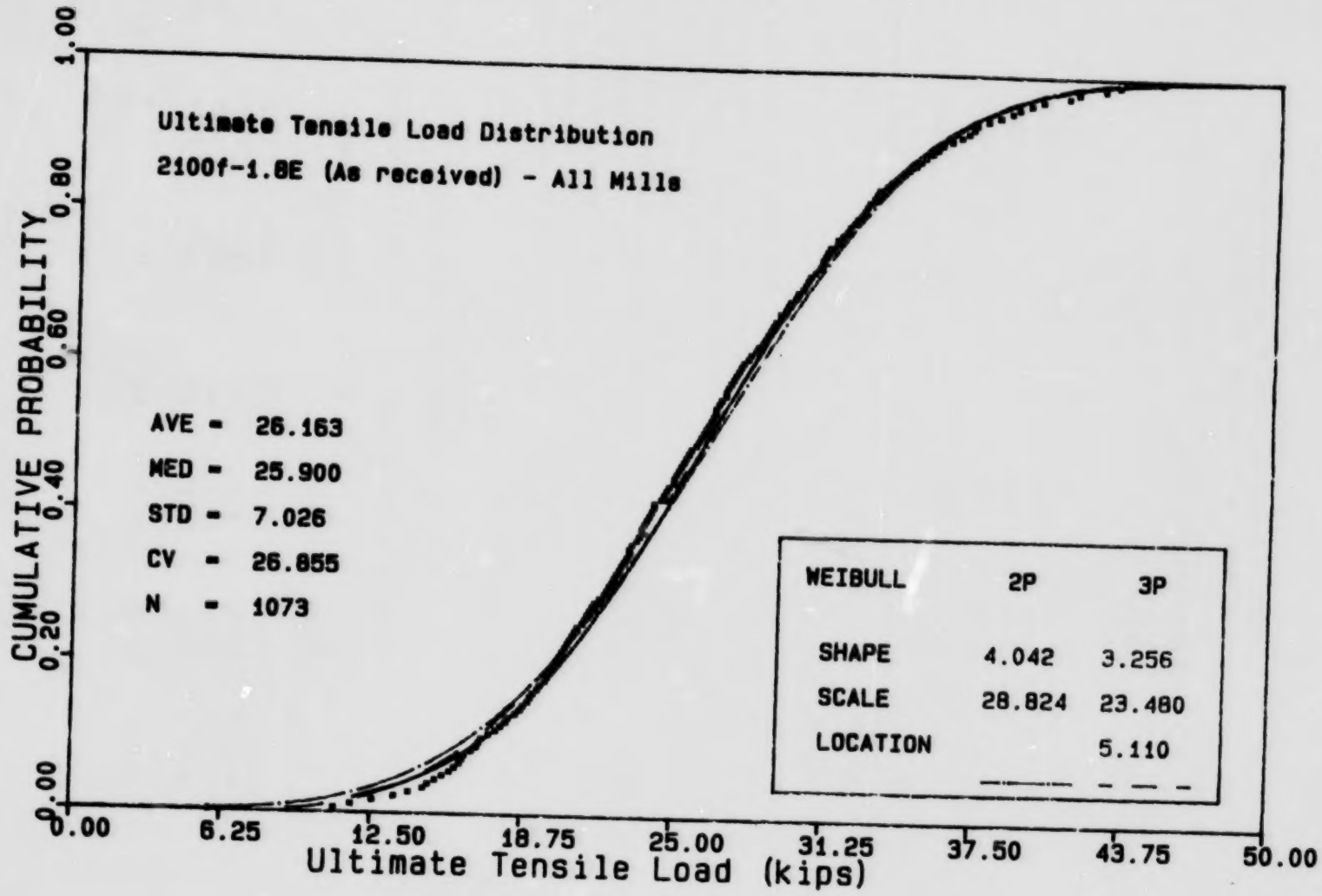


FIGURE 8. Ultimate Tensile Load Distribution for material from all four mills.

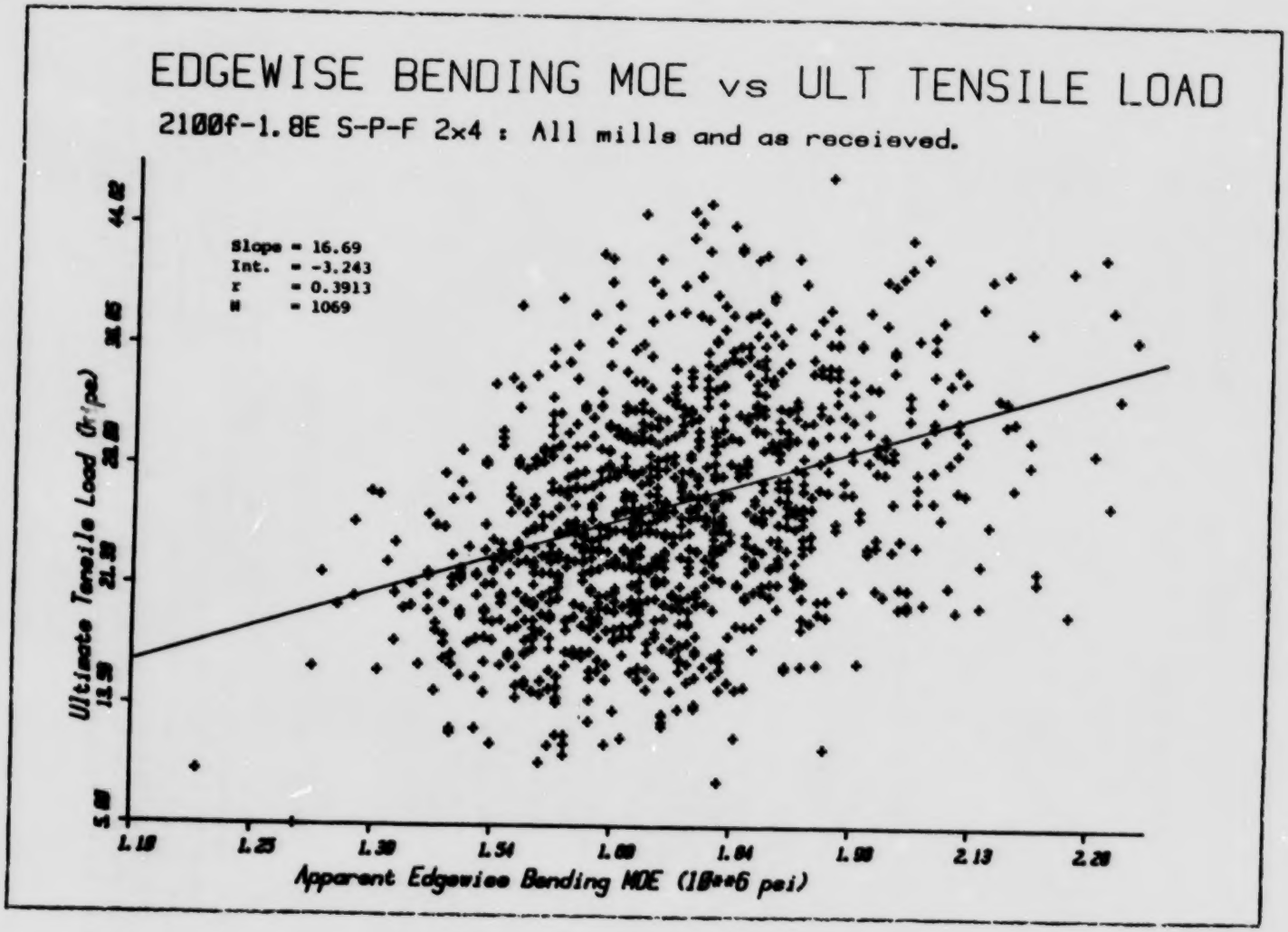

EDGEWISE BENDING MOE vs ULT TENSILE LOAD
2100f-1.8E S-P-F 2x4 : All mills and as received.
Slope = 16.69
Int. = -3.243
r = 0.3913
N = 1069
Ultimate Tensile Load (lb/psi)
Apparent Edgewise Bending MOE (10**6 psi)

FIGURE 9. Edgewise Bending MOE vs. Ultimate Tensile Load for all material as received.

TABLE 8 - 5th Percentile Ultimate Tensile Load

	Ongrade material only		Material as received	
	5th percentile (kips)	N	5th percentile (kips)	N
Mill A	14.4	270	13.8	293
Mill B	15.9	237	15.4	260
Mill C	18.9	242	18.7	260
Mill D	18.7	233	16.2	260
Total	16.0	982	15.4	1073

Code requirement: 5th percentile ultimate load = 17.27 kips

6.5 Failure Coding

Each specimen was described using the Forintek Failure coding scheme. Details of the coding scheme is given in Appendix C. From this, four parameters were calculated for failures due to knots: percentage of the cross-section displaced by the knot; percentage of the narrow or wide face displaced by the knot; knot diameter; and equivalent distance of clear wood between the knot and the narrow or wide face.

The specimens are classified according to the knot class causing failure and are arranged within each table with the four corresponding parameters in ascending order of tension failure load. These tables are included in Appendix D for each of the knot classes encountered. The column describing the grade indicates if the piece was rejected, and if so, using which set of rules. The grade column also shows whether the failure defect was the grade controlling defect. When considering failures, boards are only considered rejected by NLGA visual rules if the failure defect is, the grade controlling defect.

6.6 Matching of Worst Defect to Failure Defect

From the results of the 400 NLGA ongrade pieces tested in Phase I and the 90 NLGA offgrade pieces tested in Phases I and II, the visual grading process was found to be only successful in matching the worst defect with the failure defect in 27% of the ongrade material but 59% of the offgrade material. This is probably because offgrade or weak boards tend to have dominant defects while strong boards have small defects. The statistics on the matching of worst defect with the failure causing defect are given in Table 9.

Table 9 - Number of Times Worst Defect is Failure Defect
(graded to NLGA visual requirements)

	Ongrade material only		Offgrade material only	
	Sample size	Match	Sample size	Match
Mill A	100	27	27	19
Mill B	100	31	23	9
Mill C	100	24	18	11
Mill D	100	27	22	14
Total	400	109	90	53

6.7 Visual Overrides

After testing the samples from a bundle in Phase I or II, pieces below a cutoff point of 20 to 25 kips (90 to 100 kN) were laid out on the plant floor and photographed. Floor space limitations at the Wood-I plant did not permit all the specimens to be photographed.

6.7.1 Phase I

At the conclusion of Phase I, there did not seem to be a problem with class 2, 3 and 9 knots. There was a large number of class 8 and 10 knots failing below the specified 5th percentile tensile load. This prompted establishing a visual override for class 8 and 10 knots. Knot classes encountered in Phase I are given in Table 10.

Table 10 - Knots Classes Encountered in Phase I
(NLGA ongrade material only)

Knot Class	Sample Size	Number Below 5th* Percentile	% of Sample Below 5th* Percentile
1	18	1	5.6
2	14	0	0.0
3	58	3	5.2
4	18	0	0.0
5	0	0	0.0
6	0	0	0.0
7	0	0	0.0
8	49	8	16.3
9	31	1	3.2
10	86	8	9.3
Total	274	21	7.7%

* Specified 5th percentile tensile load = 17.27 kips.

Analysis of the description of failures due to class 8 knots did not indicate any pattern. It was then decided to tighten the existing interpretation of the NLGA rule for edge knots: instead of requiring at least an equivalent clear wood distance of 1/6 the knot diameter between the edge and the knot, the distance was increased to 1/4 the knot diameter. This would at least give an indication of whether the number of ongrade pieces was sensitive to the interpretation for edge knots. Also, the rule was easy to use since it was similiar to the existing rule.

A new rule for class 10 knots displacing more than 25% of the cross-section was also introduced after Phase I. Analysis of Phase I results indicated that four out of ten pieces failing below the specified 5th percentile load had knot displacement 33% or higher. Although class 10 knots include all knots and knot combinations not covered in class 1 to 9, the defect of interest was the case when the pith is present and several small knots go into the pith as shown in the figure illustrating class 10 knots in Appendix C.

The class 10 rule was based on a formula which assumed that the pith was in the center of the cross-section and that all knots were triangular. It can be shown that for such a set of knots to displace less than 33% of the cross-section, twice the sum of the narrow face knot diameters plus the sum of the wide face knot diameters should be less than 1.3 times the depth. When this rule was applied in Phase II, 1.0 times the depth was used instead of 1.3 times the depth. This rule applies only to 2x4's.

6.7.2 Phase II

Increasing the class 8 knot requirements for equivalent clear wood distance did not reduce the number of failures below the specified 5th percentile tensile load due to class 8 knots. In all of the pieces rejected because of this new class 8 requirement, none of the failures took place at the class 8 knot in question. In addition, 31 of the class 8 knot failures in Phase II did not meet this new rule and 9 of these were below the specified 5th percentile tensile load.

The class 10 rule also did not perform well. Seven boards graded for Phase II testing did not meet this new rule; but when tested, all of these boards had failure loads above the specified 5th percentile load and failed at a defect other than the class 10 defect causing the piece to be rejected. One drawback of the new class 10 rule was that several sections along the board had to be evaluated (summing knot diameters around the perimeter of the section). This made the rule time consuming to use and in several cases, caused the grader to miss other and more serious defects in the board.

After completing the testing in Phase II, four visual overrides were established based on the results of Phase I and II testing. Overrides for class 3 and 9 knots were established along with a simpler override for class 8 knots. The results still indicate that any rule limiting the total knot displacement at a cross-section to 33% is valid; finding an efficient visual rule, however, is difficult.

The visual overrides are given table 11.

TABLE 11 - Visual Override Rules by Knot Class for 2100f-1.8E MSR Lumber

Class	Rules for rejection**
1	Not required.
2	Not required.
3	Reject if knot is greater than 1/5 of the wide face AND is wholly or partially within the outer third of the board width.
4	Not required.
5	Not required.
6	Not required.
7	Not required.
8	Reject if the knot diameter is greater than 2/3 inch regardless of the volume of undistorted wood between the knot and the edges of the wide face.
9	Reject if knot displacement (= knot length * average knot diameter) is greater than 15% of the specified cross-section area.
10	Reject if total knot displacement at a cross-section is more than 33% of the specified cross section.

** These rules are in addition to the NLGA visual grading rules for 2x4 2100f-1.8E S-P-F lumber as interpreted by the lumber manufacturing associations involved in this study. These may not apply to other dimensions although knot size limits are presented as fraction of overall board cross-section dimensions.

Table 12 presents the results of applying the visual overrides along with existing NLGA visual rules to the sample. Material from all four bundles were combined, analyzed and grouped according to the knot failure class. The table gives an indication of the number of pieces rejected by either the NLGA visual rules or the new visual overrides but failing at loads above the specified 5th percentile tensile load.

Consider the boards failing from class 8 knots. 159 boards failed with class 8 knots as the primary failure defect and 22.0% of these boards failed below the specified 5th percentile tensile load. After regrading according to the NLGA visual rules, 27 boards (10+17) were rejected. Of these 27 pieces, 10 were below while 17 were above the specified 5th percentile load. If the visual overrides were applied along with the NLGA visual rules, a total of 62 pieces would be rejected (24+38) where 24 will be above and 38 will be below the specified 5th percentile tensile load. After applying the NLGA visual rules and new visual overrides, 97 of the 159 boards are left and 11.2% of the remaining pieces have failure loads below the specified 5th percents.

Ultimate tensile load distributions for failures due to Class 1, 2, 3, 4, 8, 9 and 10 knots are given in Figures 10 to 16, respectively.

TABLE 12 - PERFORMANCE OF VISUAL OVERRIDE RULES FOR 2100f-1.8E MSR LUMBER

Knot Class	Sample Size	% of Samples Below 5th*	No. Rejected (NLGA) Below 5th*	No. Rejected (NLGA) Above 5th*	No. Rejected (NLGA+new) Below 5th*	No. Rejected (NLGA+new) Above 5th*	New Sample Size	% of Remaining Below 5th*
1	36	5.6	0	0	0	0	36	5.6
2	53	9.4	4	9	4	9	40	2.5
3	129	9.3	0	0	10	26	93	2.2
4	48	4.2	1	0	1	0	47	2.1
5	0	0.0	0	0	0	0	0	0.0
6	0	0.0	0	0	0	0	0	0.0
7	0	0.0	0	0	0	0	0	0.0
8	159	22.0	10	17	24	38	97	11.2
9	80	6.3	0	3	3	8	69	3.0
10	238	10.9	3	2	12	6	220	6.4
Total	743	11.7%	18	31	54	88	602	5.5%

* Specified 5th percentile tensile load = 17.27 kips.

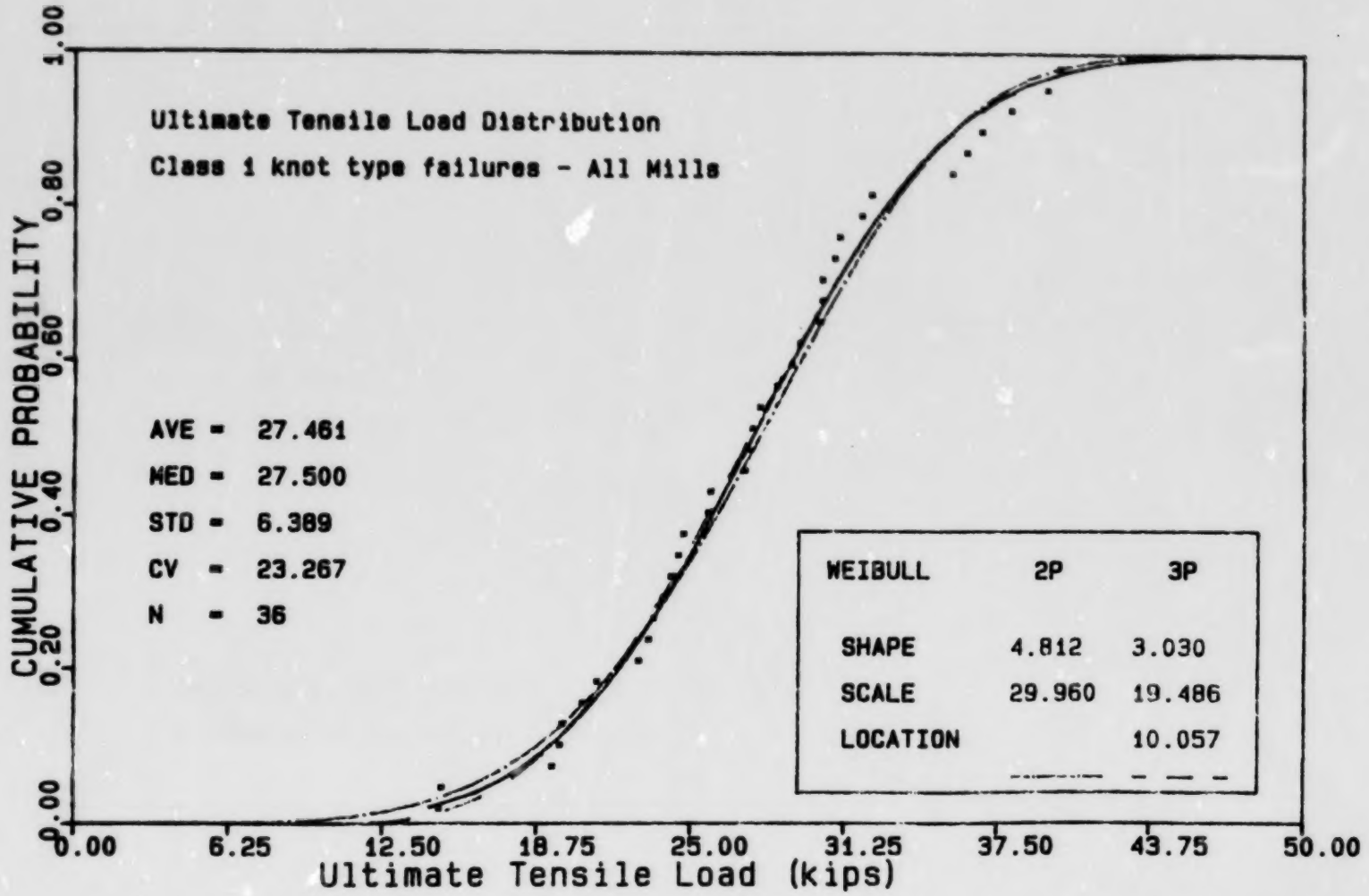


FIGURE 10. Ultimate Tensile Load Distribution for Class 1 Knot Type Failures.

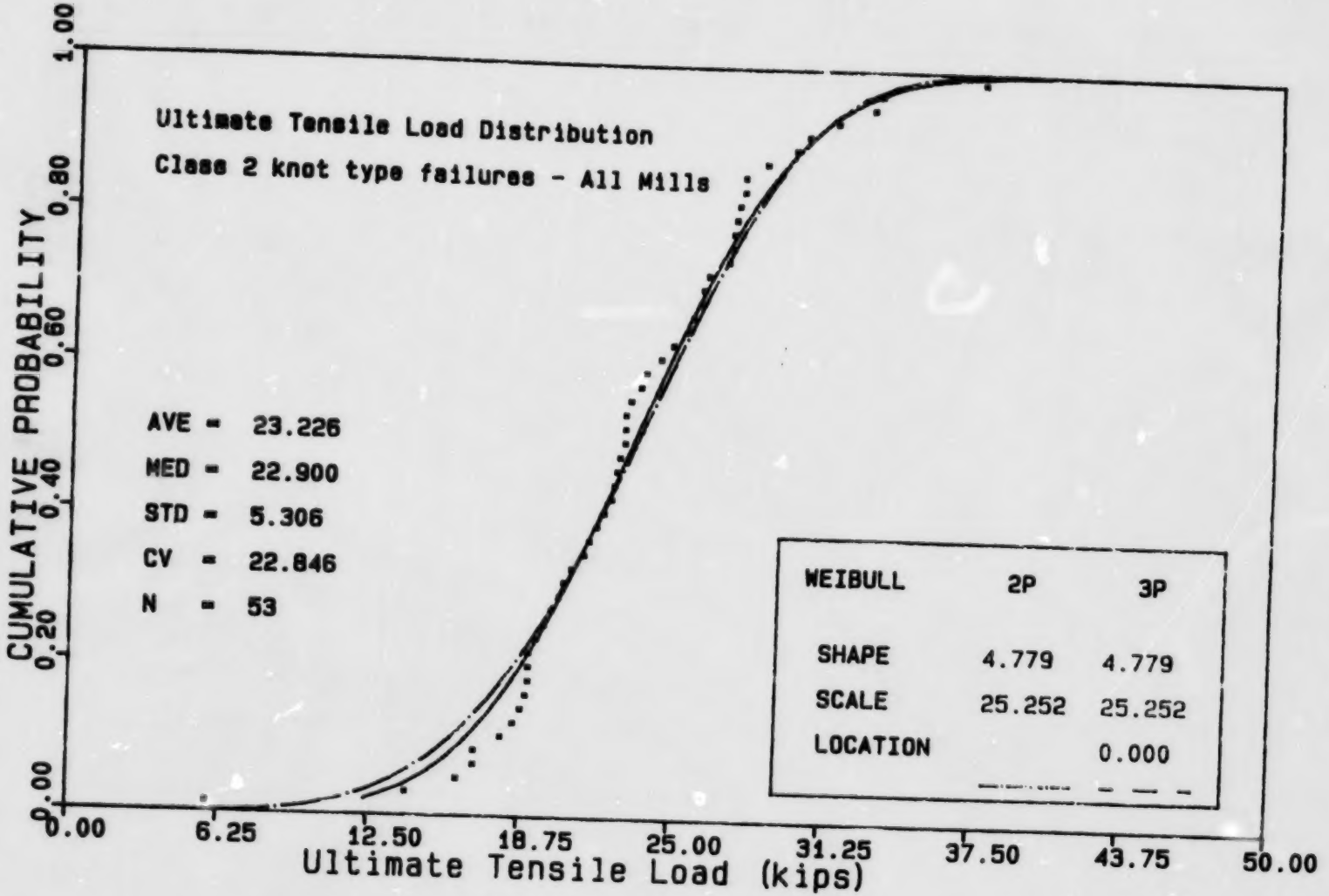


FIGURE 11. Ultimate Tensile Load Distribution for Class 2 Knot Type Failures.

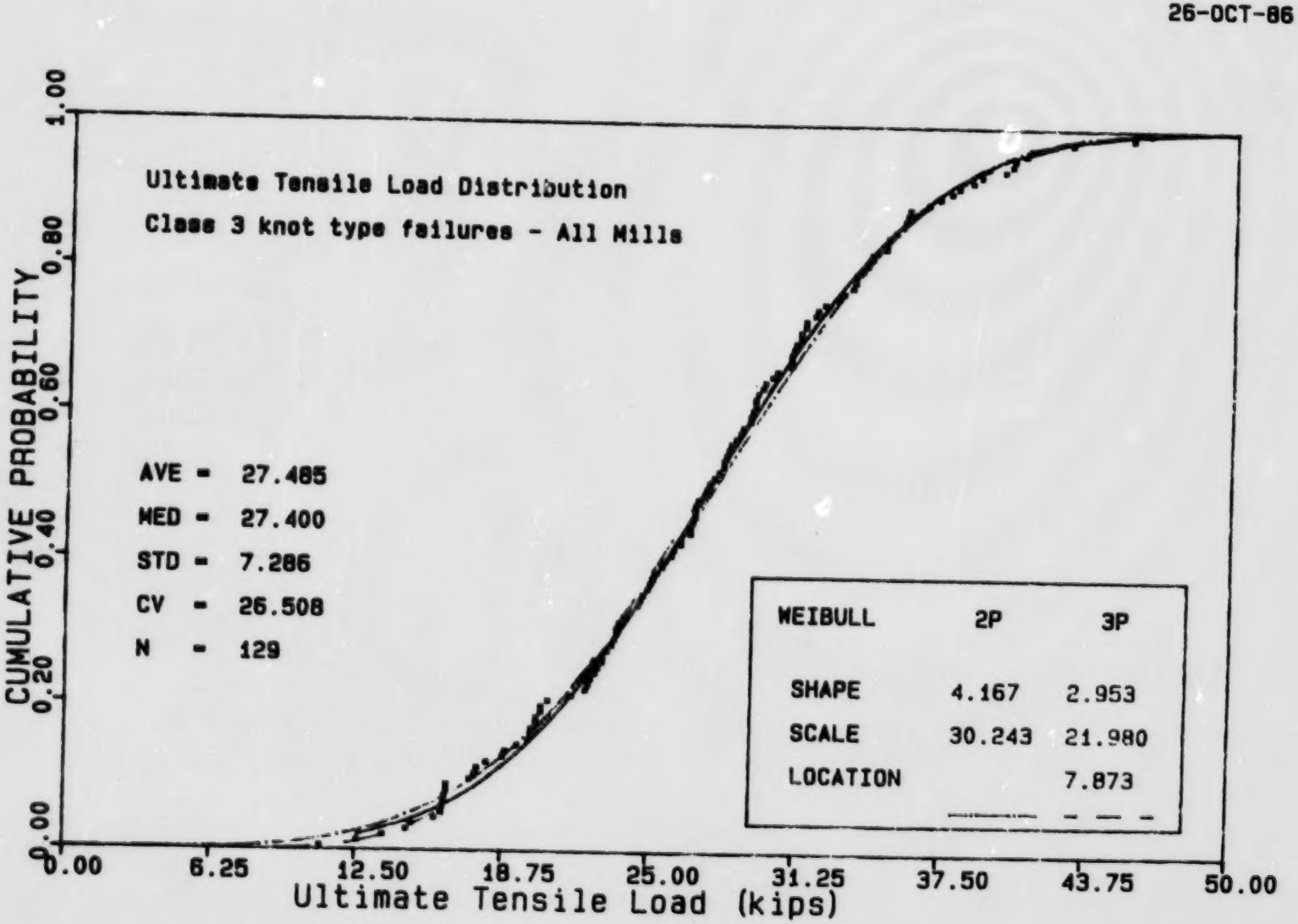


FIGURE 12. Ultimate Tensile Load Distributions For Class 3 Knot Type Failures.

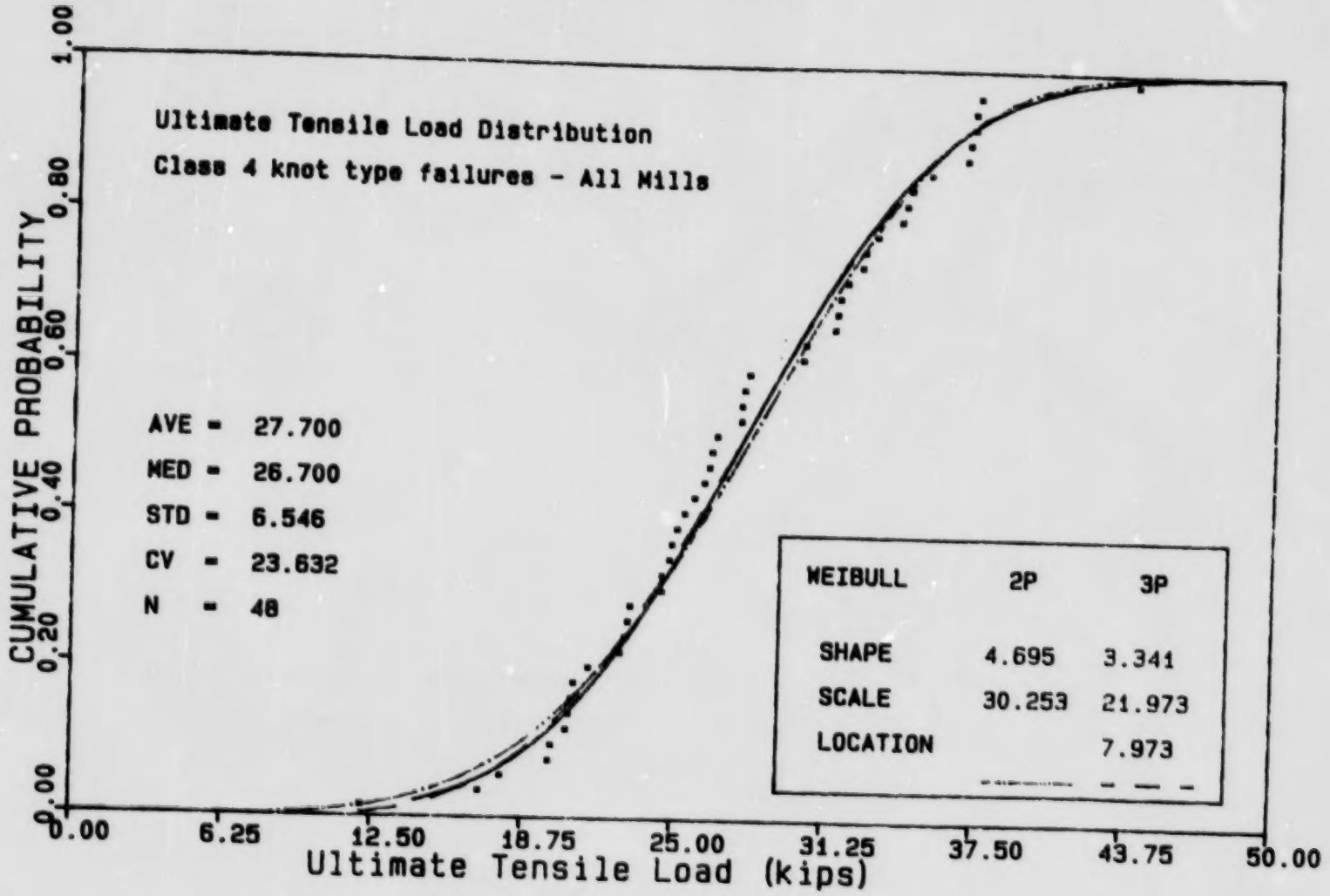


FIGURE 13. Ultimate Tensile Load Distributions For Class 4 Knot Types Failures.

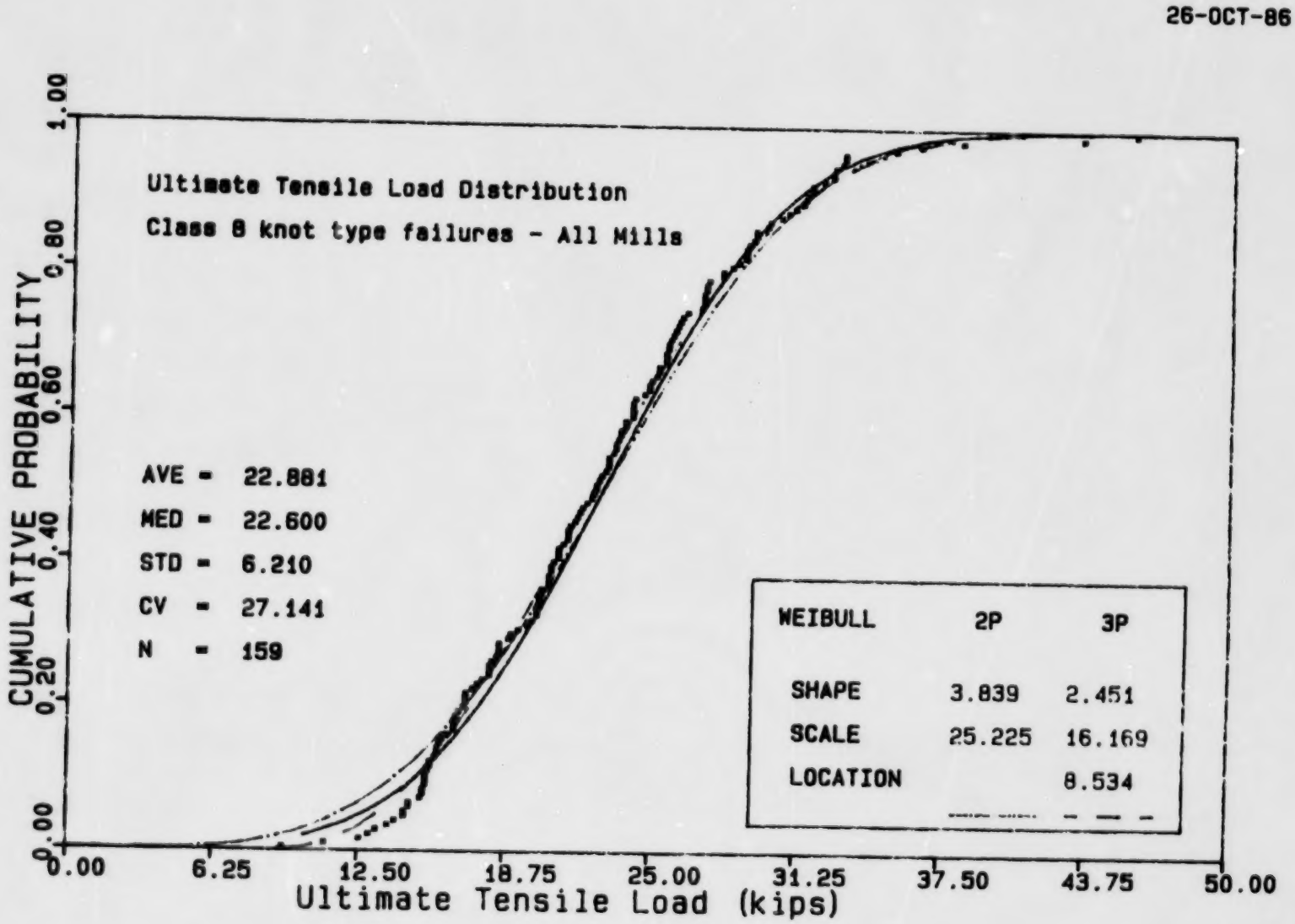


FIGURE 14. Ultimate Tensile Load Distribution For Class 8 Knot Type Failures.

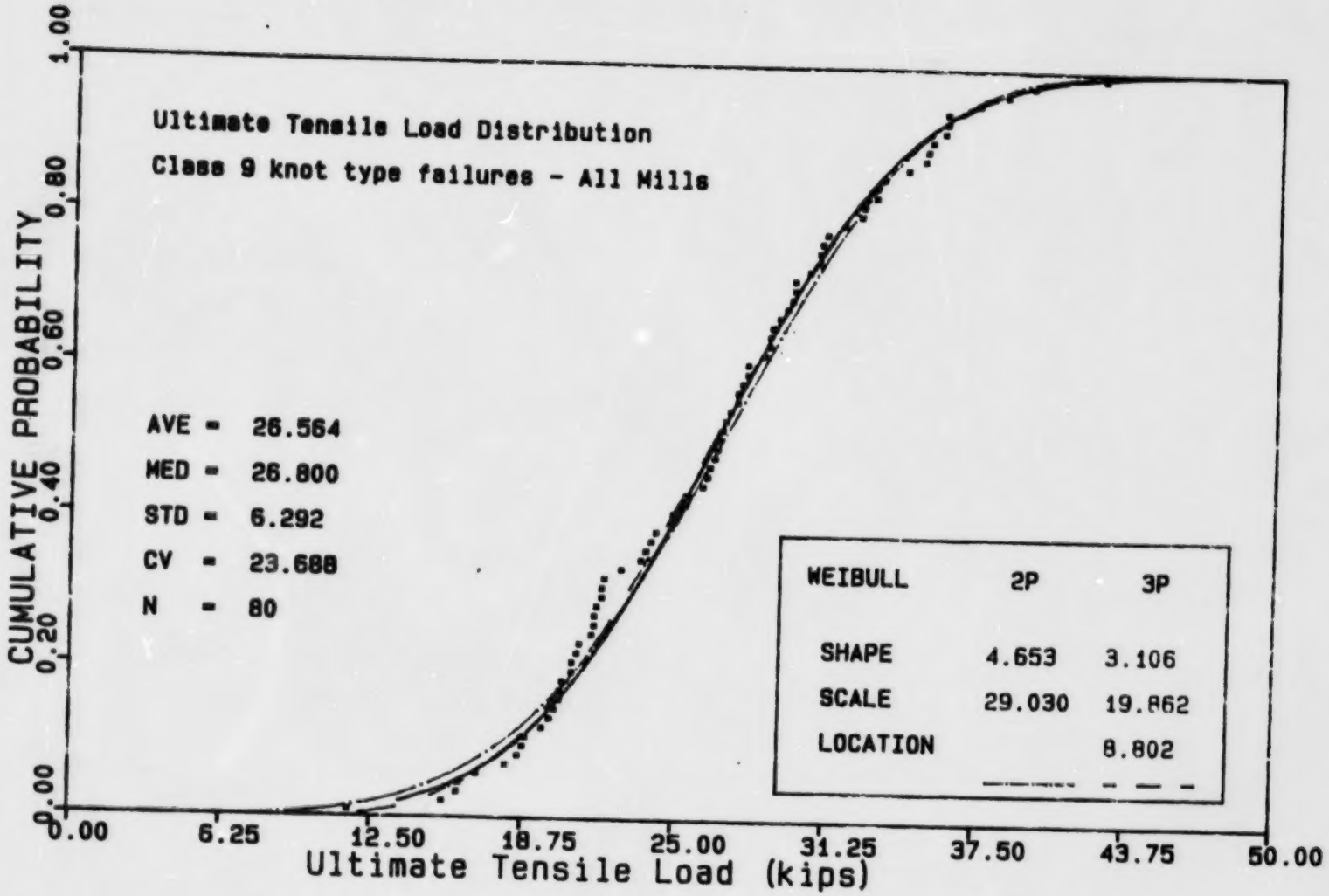


FIGURE 15. Ultimate Tensile Load Distributions for Class 9 Knot Type Failures.

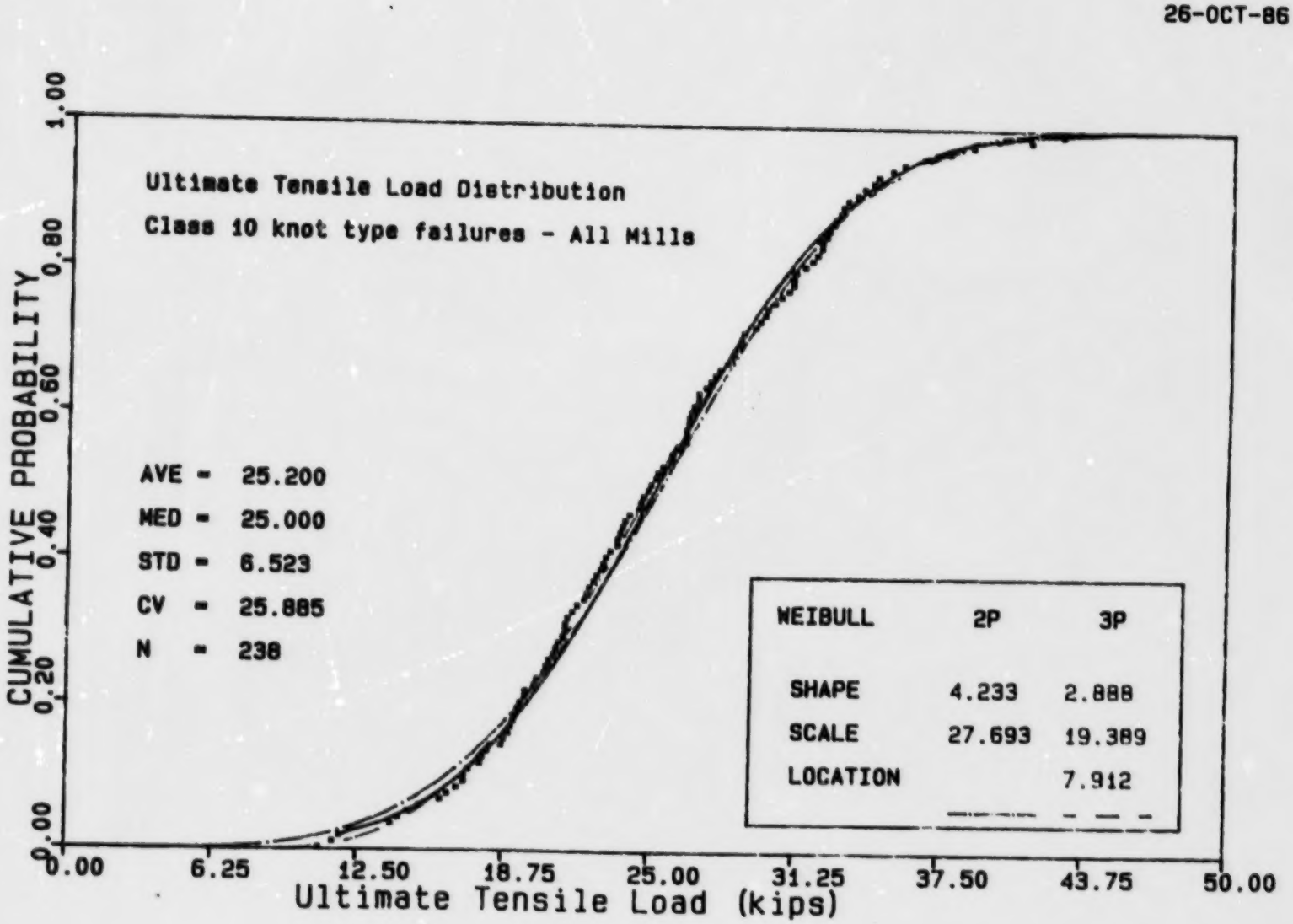


FIGURE 16. Ultimate Tensile Load Distributions for Class 10 Type Knot Failures.

6.8 Other Causes of Failure

A summary of other failures and frequency of occurrence are listed in Table 13.

TABLE 13 - Other Failures

Code	Description	Number of occurences	Number below 5th percentile
23	Knot cluster	1	0
24	Slope of grain (wide face)	71	9
25	Grain deviation	25	6
26	Cross grain (narrow face)	3	1
27	Shake and checks	5	2
28	Splits	0	0
31	Unsound wood	3	0
32	Pinworm holes	0	0
33	Grub holes	1	0
34	Teredo holes	0	0
35	Bark pockets	7	1
36	Pitch pocket	0	0
37	Wane	0	0
42	Compression wood	2	0
43	Burl	4	2
45	Machine damage	0	0
46	Falling breaks	4	0
47	Breaks	0	0
48	Deviated pith	4	1
50	Longitudinal shear	9	1
51	Compression	0	0
52	Tension and compression	0	0
53	Tension	91	0
54	Lateral buckling	0	0
55	Brash	60	1
58	Knot	0	0
59	Rate of growth	0	0
60	Clear wood or small defects	0	0
61	Slip in grips (no failure)	40	0
	TOTAL	330	24

There were two predominant causes of failures at loads below the specified 5th percentile load other than knots: slope of grain on the wide face and grain deviation.

Seventy-one failures were attributed to slope of grain. Of these, nine were below the specified 5th percentile load level. There does not appear to be a upperbound on the slope of grain of pieces failing below the specified 5th percentile load level. Failure which appear to be due to slope of grain may be triggered by initial failure around knots where the local slope of grain may be higher than the average slope of grain in the board.

Nevertheless, an allowable slope of grain of 1 in 10 can be applied to reduce the portion of the sample below the specified 5th percentile load from 12.7 percent to 8.3 percent (see Appendix E, Table E-1). This is actually the maximum slope of grain permitted in visually graded No. 1 lumber. As in visually graded lumber, slope of grain is difficult to quantify during production but for MSR lumber, slope of grain is not checked directly.

Grain deviation is similar to slope of grain in that it is difficult to quantify visually. Using the Forintek failure coding scheme, grain deviation is expressed as the percentage of the specified cross-section area where the deflection or local slope of grain is greater than 1:4. Although 24 percent of the 25 specimens which failed due to grain distortion were below the specified 5th percentile load level, there does not appear to be any pattern indicating the amount of grain distortion which can be permitted (see Appendix E, Table E-2).

6.9 Results by Mill

The following tables, 14a to c, 15 and 16, summarizes the defects causing failure for each mill and how the number of these defects are affected by NLGA visual requirements and the proposed visual overrides. These figures assume that a grader is able to match the worst defect with the failure defect. The rule restricting slope of grain to 1 in 10 has also been included in the following results.

Table 14a - Material As Received

	<---------- Knot Class ---------->												
Mill	1	2	3	4	5	6	7	8	9	10	SOG	GDev	Other
A	9	6	28	17	0	0	0	48	25	120	5	2	33
B	8	22	40	6	0	0	0	42	13	37	16	9	67
C	7	10	20	10	0	0	0	20	26	64	16	9	78
D	12	15	41	15	0	0	0	49	16	17	34	5	56
Total	36	53	129	48	0	0	0	159	80	238	71	25	234

Table 14b - After Checking Exisitng NLGA Visual Requirements

	<---------- Knot Class ---------->												
Mill	1	2	3	4	5	6	7	8	9	10	SOG	GDev	Other
A	9	4	28	16	0	0	0	45	25	117	5	2	33
B	8	18	40	6	0	0	0	35	13	36	16	9	67
C	7	6	20	10	0	0	0	16	24	63	16	9	78
D	12	12	41	15	0	0	0	36	15	17	34	5	56
Total	36	40	129	47	0	0	0	132	77	233	71	25	234

Table 14c - After Checking Existing NLGA and New Visual Requirements

	<---------- Knot Class ---------->												
Mill	1	2	3	4	5	6	7	8	9	10	SOG	GDev	other
A	9	4	16	16	0	0	0	30	21	107	5	2	33
B	8	18	33	6	0	0	0	25	12	34	10	9	67
C	7	6	18	10	0	0	0	13	22	62	9	9	78
D	12	12	26	15	0	0	0	29	14	17	24	5	56
Total	36	40	93	47	0	0	0	97	69	220	48	25	234

SOG = Slope of grain (wide face) ; GDev = Grain deviation

Table 15 - Final Results by Mill and Total
Above and Below Specified 5th Percentile Tensile Load

Mill	As Received		After NLGA		After NLGA + New	
	Below 5th	Above 5th	Below 5th	Above 5th	Below 5th	Above 5th
A	57	236	52	232	27	216
B	25	235	21	227	10	212
C	9	251	7	242	6	228
D	20	240	13	230	9	201
Total	111	962	93	931	52	857

Table 16 - Percentage of Sample Below Specified
Fifth Percentile Tensile Load

Mill	As Received	After Regrading (NLGA)	After Regrading (NLGA + New)
A	19.5	18.3	11.1
B	9.6	8.5	4.5
C	3.5	2.8	2.6
D	7.7	5.4	4.3
Total	10.3	9.1	5.7

7. DISCUSSIONS

7.1 Effect of Rate of Loading

For in-grade studies, a mean time to failure of one minute or a loading rate of about 4000 psi/min (27.6 MPa/min) is desirable. In fact, NLGA SPS-2 specifies loading rates of 16,000 psi/min (110.4 MPa/min) or less for bending strength tests. However, in this study, a mean time to failure of 10 to 15 seconds could only be achieved. This is equivalent to a loading rate of 24,000 psi/min (165.6 MPa/min) and is well above the recommended loading rate but less than impact loading rates (measured in fractions of a second).

McLain et al (1976) found that fast loading rates (6000 psi/min) in tension parallel to the grain resulted in "moderate" strength increases. The study was conducted with No. 2 KD15 southern pine 2x6's. Furthermore, the study suggests that loading rate effects are more "significant" for higher quality lumber. In other words, ignoring loading rate effects in our study would mean the measured strength would be higher than the strength obtained using standard loading rates.

On the other hand, two studies (Strickler et al, 1973 and Karacabeyli, 1986) found that there was no significant effect due to rate of loading. In the first study, Strickler examined the rate of loading effects on the tension paralle-to-grain strength of clear hemlock and Douglas-fir specimens at loading rates from 1,200 to 52,800 psi/min (8.3 to 364.3 MPa/min). In the second study, tests were conducted at Forintek on spruce lumber at 3 second and 1 minute mean time to failures.

Bending studies with hemlock found the bending strength to increase with increasing rate of loading (Foschi, et al, 1982). For time to failures in the range of 10 to 15 second, however, the failure loads were found to be less than 4% higher than tests conducted with an average 1 minute time to failure.

The above studies suggest that high loading rate will result in either higher strengths or no changes in strength. Thus ignoring the loading rate effect would not change the conclusions about the ultimate tensile load results. At most, adjusting for the rate of loading effect would make the 5th percentile tensile load even lower than what was found in the test.

7.2 Application of Visual Overrides

The efficacy of the visual overrides depends not only on the rules but also on how well the grader is able to find the failure defect to apply the appropriate rule. Although the grader may be able to find the worst defect, this defect may not correspond to the failure defect. This discrepancy may be due to the inability of the grader to assess the relative severity of the various defects in a board (for example, slope of grain versus knot diameter). The success of any visual grading rules will also depend on whether the grading is done at mill production speeds or at the end user's facilities just prior to usage.

The ability of the grader to match worst defect with the failure defect increased when grading ongrade material as opposed to offgrade material. This is likely due to the presence of dominant defects which are easier to detect and tend to appear in weak boards. Although it is fortunate that the grader's ability is higher when grading weaker board, this human characteristic does cast some doubts on the reliability of visual grading when it is applied to high grade material.

Application of two new visual rules in the second phase of the study indicated several problems. Since the rules are new, the grader may tend to concentrate more on the new rules and may miss defects normally detected using just the old rules. This may be a temporary problem and may be gradually overcome as the grader gains more experience with the rule.

However, rules requiring a series of measurements do not appear to be practical, although it may be desirable. Take for example the Class 10 rule established after Phase I for lodgepole pine board containing the pith. Unlike spruce, branches in lodgepole pine tend to grow at regular intervals along the tree. As a result, there may be several sections along the board where the Class 10 rule must be checked, and the severity of the defects are difficult to estimate without direct measurement.

Another problem with visual grading is that the size of the knot as it appears on the faces of the board is not always an accurate indicator of the amount of straight grained wood displaced--the actual displacement of the knot may not be well defined in terms of the dimensions as measured by the grader. For class 10 knots with the pith present, the knot dimensions on the sufrace of the board may reflect the diameter of the knots but the actual displacement may be difficult to calculate. In Figures 5a and 5b, the knot diameters are well defined, but unless the pith is located, the total knot displacements cannot be determined accurately. When the knots are poorly defined as is Figure 5c, determining total displacement visually is nearly impossible without breaking the board. Figure 5d is an example of a well defined class 2 knot. Here, the amount of clear straight grain wood displaced can be determined directly from the knot dimension. Figures 5e-h are other examples of knots which are well or poorly defined.

These visual grading deficiencies can be compensated for by adjusting the allowable stresses and design factors. However, this is economical only if visual grading can be consistently applied. Otherwise, the result will be similar to visually graded lumber where large safety factors are required, thus, much of the material is inefficiently utilized.

FIGURE 17a.

Well defined class 10 knot (small knots) with pith present, but difficult to measure.

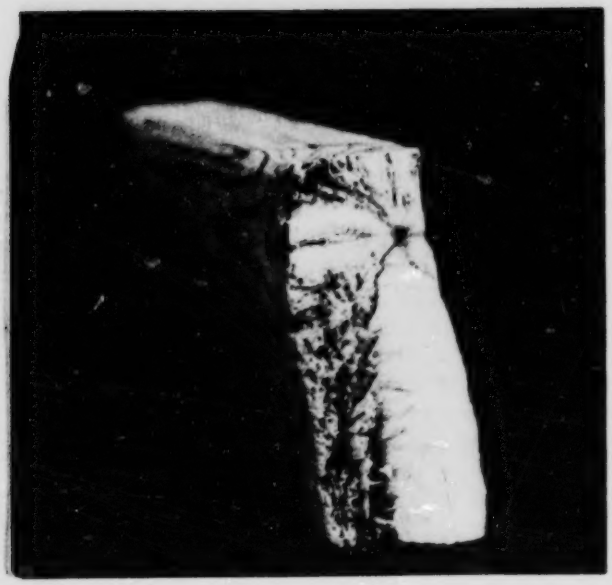


FIGURE 17b.

Well defined class 10 knot (large knots) with pith present, but difficult to measure. Note that lower knot is not triangular

FIGURE 17c.

Poorly defined class 10 knot with pith present.

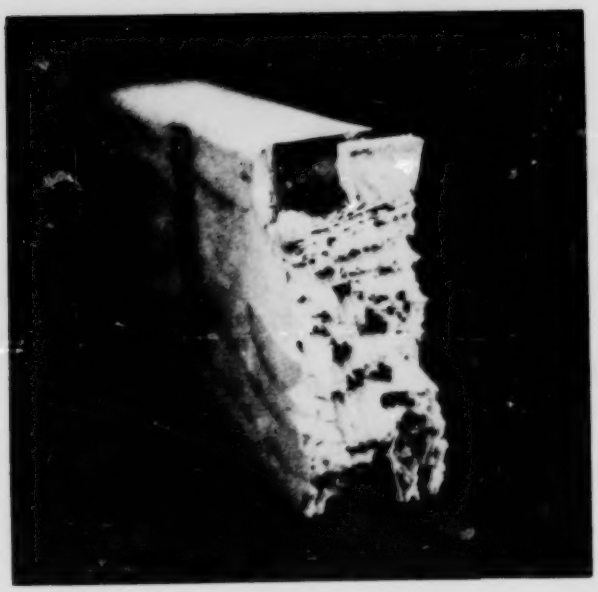


FIGURE 17d.

Well defined class 2 (edge) knot.

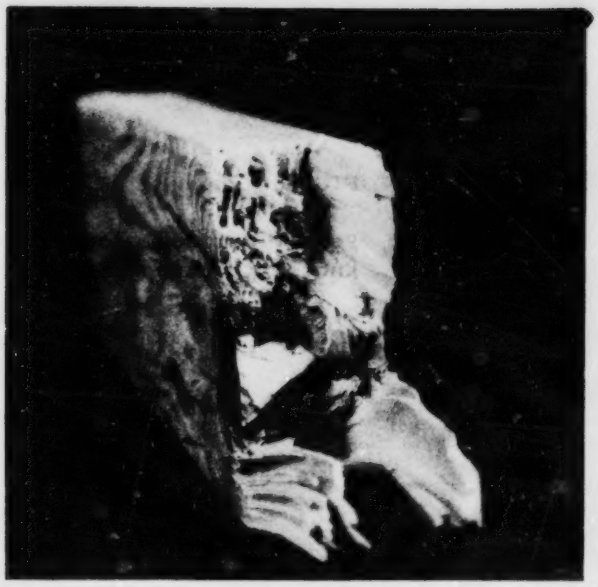


FIGURE 17e.

Poorly defined class 3 (wide face) knot.

FIGURE 17f.

Poorly defined class 3 (wide face) knot.

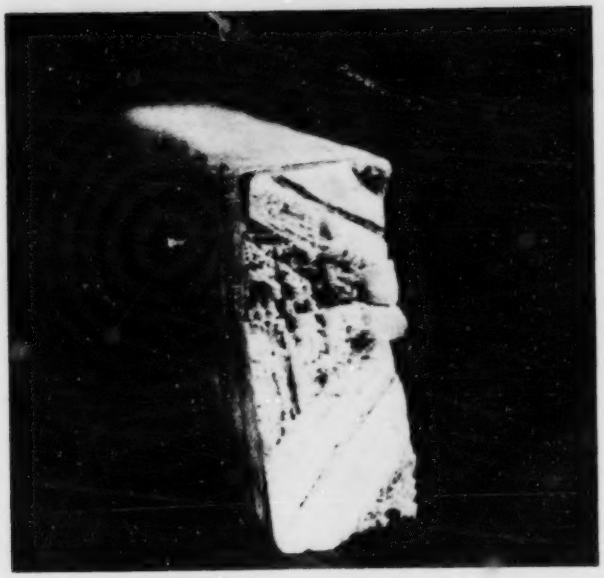


FIGURE 17g.

Two well defined class 8 knots in the same cross-section.

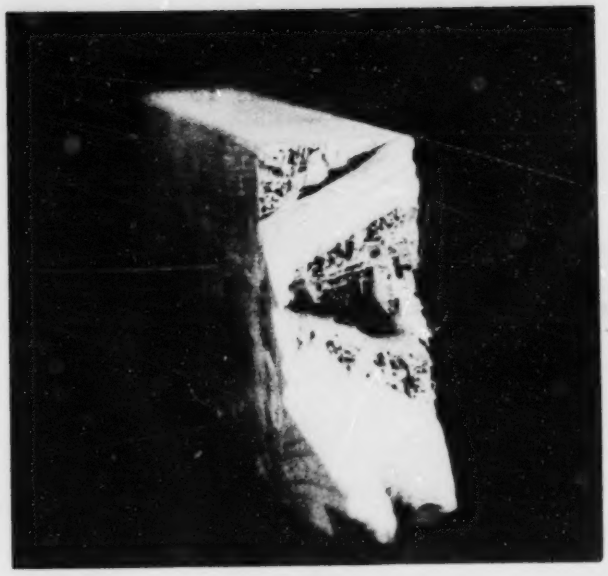


FIGURE 17h.

One well defined and one poorly defined class 8 knots in the same cross-section.

8. CONCLUSIONS

Of the four bundles tested, three did not meet the specified 5th percentile tensile load. Regrading the material according to existing NLGA visual rules did improve the strength of all the samples tested, but only marginally.

If a grader were always capable of matching the worst defect with the failure defect in a board, the visual overrides presented in this study would reduce the percentage of the sample failing (due to knots) below the specified 5th percentile tensile load from 11.7 percent to 5.5 percent. Two of the three bundles originally not meeting the specified 5th percentile tensile load met the requirements after applying the overrides.

The visual grading process is only capable of finding the strength controlling defect in 27 percent of the ongrade pieces and 59 percent of the NLGA offgrade pieces. As a result, the efficacy of the new visual overrides when applied to other sample cannot be accurately determined as yet.

9. RECOMMENDATIONS

The proposed rules including the limitation on slope of grain reduced the percentage of the sample failing below the 5th percentile load from 10.3 to 5.7 percent. These rules still need to be evaluated with unbroken pieces to see how well a grader can apply them to other samples. Thus, a study directed to the verification of visual grading overrides established at the end of Phase II is recommended.

The sample size used in Phase I was too small (total 400 pieces); problems with class 3 and class 9 knots were not revealed until Phase II which involved testing a larger sample size (total 670 pieces). A sample size of 600 to 700 pieces might ensure that the correct number of knot classes for detailed evaluation.

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APPENDIX A

PROPOSED PROCEDURE FOR STUDY

The proposed procedures are contained in the following document prepared prior to the start of the testing:

VARIABILITY OF MSR LUMBER IN TENSION

The required testing will be carried out in Jager Inc.'s Calgary plant. Cooperating in the project will be Metriguard, Alberta Forest Products Association, Forintek and Alberta Research Council. Metriguard will provide calibration checks for test equipment. Alberta Forest Products will assist with all visual grading. All testing will be provided by Jager Industries Inc.

Forintek will oversee and coordinate the project, oversee the testing, analyze the data, develop recommendations for visual override, prepare detailed report and get involved as necessary to ensure proper scientific approach. Alberta Research Council will provide technical input as required and will review the final report.

The steps in the project are:

1. Obtain one bundle (260 pieces) of 2x4x16' lumber of 2100f MSR grade from the production of 4 plants (Jager Industries) namely:
   a. Millar Western
   b. Blue Ridge
   c. Crestbrook Forest Industries
   d. Weyerhaeuser
2. Deliver lumber to Wood Products Division (Jager Industries).
3. Sort out 100 pcs from each bundle ensuring compliance with NLGA rules for MSR (AFPA):
   a. Check grade, discard off grade
   b. Measure moisture content
   c. Measure size
   d. Identify species
   e. Record visual quality level
   f. Identify worst defect and its location
4. Edge E-rate 100 pcs from each bundle in bending (Jager Industries for testing and Metriguard for calibration).
5. Test the selected 100 pcs from each bundle in full span tension (testing by Jager Industries, Forintek will oversee, calibration by Metriguard).
   a. Record failure load
   b. Determine tension MOE

6. Record the information about the defect causing the failure (Forintek and AFPA).
   a. Defect that triggers failure - knot plot
   b. Location of failure defect
   c. Is it related to worst defect
7. Data analysis for 100 pcs from each bundle (Forintek).
8. Lay out each piece in ranked order of failure load (Forintek).
9. Try imposing visual override in increments (Forintek).
10. Calculate 5th percentile tension load for each increment, record number of pieces rejected for each type of defect (Forintek).
11. Define visual override limits and record rejects (Forintek/AFPA).
12. Grade the remaining (160 or less) pieces from each bundle applying override criteria (AFPA/Forintek).
    a. Check grade, discard off grade using override criteria defined in item 11.
    b. Measure MC
    c. Measure size
    d. Identify species
    e. Record visual quality level
    f. Identify worst defect and its location
13. Test samples graded in step 12, using the override criteria, steps 4-6.
14. Analyze the data (Forintek)
15. If override criteria defined for first 100 pieces for each bundle is verified, stop here, otherwise proceed with step 8-11 to fine tune visual override established in step 11.
16. Prepare a detailed report of each step supported by technical data and analysis, draw conclusions and suggest appropriate recommendations (Forintek).
17. Review the report (ARC)
18. All cooperators will meet and discuss the report.

June 13, 1986.

APPENDIX B

SUMMARY

EQUIPMENT CALIBRATION FOR JAGER STUDY OF MSR LUMBER

SUMMARY

EQUIPMENT CALIBRATION FOR JAGER STUDY OF MSR LUMBER

by

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August 20, 1986

SUMMARY

EQUIPMENT CALIBRATION FOR JAGER STUDY OF MSR LUMBER

by

Friend K. Bechtel, Director of Research
Metriguard Inc. Pullman, WA
August 20, 1986

I. BENDING TESTER

The bending tester consisted of a Jager built third point loading framework with loading in the vertical direction. Loading was downward at the third points. For this test, the machine was modified so that slip plates on both end reaction pads and one of the third points on the loading beam had teflon bearings. The end reaction points were not properly aligned, so additional teflon spacers were used under the slip plates.

An axial degree of freedom at the end reaction points would be desirable for purposes of accommodating any twist that might exist in the lumber. However, the error induced in the measurement by not accommodating twist is probably not large for the relatively twist-free lumber to be tested. The E-measurement of a twisted piece would be slightly smaller on this machine than on one which contained an axial degree of freedom.

To prevent errors in the measurement from compliance in the frame and in the load cell (located under one end reaction support) and its mounting, a bridge to support the deflection measuring dial indicator was manufactured and slung between the end point reaction supports. The dial indicator measured the deflection of the lumber in the center of a 73.5 inch test span, and the load cell measured the load at one of the end point reaction supports.

The operative equation is:

$$F = 28.1739\ EID/L^3 \qquad (1)$$

where

F is the force in pounds at the load cell.

E is the beam modulus of elasticity in psi.

I is the beam cross-section moment of inertia about the neutral axis in $inch^4$.

L is the test span length-- in this case 73.5 inches.

D is the centerspan deflection in inches.

An aluminum test bar with cross-section 1.5" x 1.5" calibrated by Warnock Hersey on 4/3/86 was used to verify calibration of the bending tester. The Warnock Hersey calibrated value for the test bar EI product was:

$$EI = 4{,}055{,}211 \text{ lb}\cdot\text{in}^2$$

The test bar was inserted in the machine, and a preload of 25 pounds (measured at the load cell) was applied. Then, increasing loads were applied to give additional deflections of 0.200, 0.300, 0.400, and 0.500 inches. The loads as measured by the load cell and the loads computed from Equation (1) are contained in Table I.

TABLE I

Deflection (inches)	Measured Load (pounds)	Difference (pounds)	Computed Load (pounds)	Difference (pounds)
0	25		25	
		58		57.55
0.200	83		82.55	
		30		28.77
0.300	113		111.32	
		29		28.78
0.400	142		140.10	
		30		28.77
0.500	172		168.87	

Although the measured difference values are about 2.2% higher than the computed values based on the test bar, no attempt was made to obtain a closer calibration. If desired the measured E values can be reduced by this percentage.

Mechanical hysteresis caused by friction was checked by loading the test bar past a preload of about 70 pounds to 0.200 inch deflection where the force reading was 128 pounds. An additional load was applied to give an additional 0.100 inch deflection. Then this load was slowly released to just undo the additional 0.100 inch deflection on the dial indicator. The force reading at this point on the way down was 124 pounds, showing the hysteresis to be 4 pounds. This was felt to indicate an acceptably low friction component of force.

Measurement Error Analysis

Measurement errors are caused by roundoff errors in each of the measurements of the E calculation as well as by systematic errors including calibration error, errors in reading dial gauge and digital panel meter, recording errors, and errors in beam cross-section.

The process chosen by the test coordinator for E measurement was to preload the specimen to approximately 60 pounds, read the dial indicator and force readout, then load the specimen to approximately another 100 pounds and again read the dial indicator and force readout. The dial indicator reading was to the nearest 0.001 inch and the force readout was to the nearest pound.

The computation for E is

$$E = 14093.4\ F/(ID)$$

$$= 14093.4\ (F_2-F_1)/(I[D_2-D_1])$$

$$= 169121\ (F_2-F_1)/(bh^3[D_2-D_1])$$

where

F_1, F_2 are first and second force measurements.

D_1, D_2 are first and second deflection measurements.

b is lumber thickness.

h is lumber width.

E is a function of F_1, F_2, b, h, D_1, and D_2. This function can be expanded in a Taylor Series about a nominal value E_o using nominal values F_{1o}, F_{2o}, b_o, h_o, D_{1o} and D_{2o} for the independent variables. Keeping only the first order terms, we can write:

$$E = E_o[1 - (F_1-F_{1o})/(F_{2o}-F_{1o}) + (F_2-F_{2o})/(F_{2o}-F_{1o})$$

$$+ (D_1-D_{1o})/(D_{2o}-D_{1o}) - (D_2-D_{2o})/(D_{2o}-D_{1o})$$

$$- (b-b_o)/b_o - 3(h-h_o)/h_o]$$

Assuming statistical independence, the variance of E is given by:

$$\mathrm{Var}E = E_o^2[\mathrm{Var}F_1/(F_{2o}-F_{1o})^2 + \mathrm{Var}F_2/(F_{2o}-F_{1o})^2$$

$$+ \mathrm{Var}D_1/(D_{2o}-D_{1o})^2 + \mathrm{Var}D_2/(D_{2o}-D_{1o})^2$$

$$+ \mathrm{Var}B/B_o^2 + 9\mathrm{Var}h/h_o^2]$$

Nominally:

$F_{2o}-F_{1o} = 100$ pounds

$D_{2o}-D_{1o} = 0.150$ inch

$b_o = 1.5$ inch

$h_o = 3.5$ inch

Due to roundoff, we have:

$\text{Var}F_1 = 1/12$ pounds^2

$\text{Var}F_2 = 1/12$ pounds^2

$\text{Var}D_1 = (1/12)(10^{-6})$ inch^2

$\text{Var}D_2 = (1/12)(10^{-6})$ inch^2

Then:

$$\text{Var}E/E_o^2 = (1/12)(10^{-4}) + (1/12)(10^{-4}) + (1/12)(10^{-6})/(0.150)^2 + (1/12)(10^{-6})/(0.150)^2 + \text{Var}b/b_o^2 + 9\text{Var}h/h_o^2$$

Neglecting thickness and width error contributions, the coefficient of variation of E is:

$$\text{cov } E = (\text{Var}E/E_o^2)^{1/2} = [(1/6)(10^{-4}) + (1/6)(10^{-6})/(0.15)^2]^{1/2} = 0.00491$$

Thus, the standard deviation of the error is about 1/2 % of the measurement-- not including width and thickness errors or other systematic errors. Because each evaluation of E required four separate numbers to be read, recorded and then entered into the computation for E, the possibility for this type of systematic error in the data should be noted.

II. TENSION TESTER

The tension tester is the Metriguard Model 412B/30 used by Jager Industries in their quality verification of each of their finger joints. Jager also owns the Metriguard Model 412 TCL Tension Calibration Link. This device is inserted into the grips of the tension tester and loaded in tension as though it were a piece of lumber. The center section of the Tension Calibration Link is a tension load cell, Strainsert Model TLLR-100/2, SN Q7054-A1 which works with a portable indicator unit,

Strainsert Model DR-1, SN Q7054-A. The Strainsert equipment, traceable to the United States National Bureau of Standards, gives a reading of force that is completely independent of the Model 412B/30 electronic unit readout. At the time of manufacture, the electronic readout unit was calibrated against the Model 412 TCL Tension Calibration Link. A copy of Figure 4 of the 412B/30 Operator's Manual showing the comparison of these readings is included in this report as Figure 1.

For this test, calibration of the Model 412B/30 Tension Tester was checked against the Model 412 TCL Tension Calibration Link. The gain of the tension tester was found to be about 20% too low, so it was increased to agree with the tension calibration link at about 50,000 pounds force. Subsequently, at 1:00 P.M. on August 15, after the first few pieces were tested and maximum force for tension E measurement was established, the system was again calibrated, but this time the calibration point used was approximately 17,000 pounds. A gain decrease of 3% was required.

Before the above gain settings were made, the load cell zero of the system was set to read zero just after the tension stroke begins with no lumber in the clamps. This technique removes from the measurement the effect of rolling friction in the power end clamp. Sensitivity of the load cell amplifier analog output is 1 volt/10,000 pounds force for the 100,000 pounds force range used during the test.

The extensometer includes a Schaevitz 1000 HR, SN 8731 LVDT and a Daytronics 3230, SN 922 Signal Conditioning and Display Unit. The extensometer was calibrated at Metriguard's plant about two weeks prior to testing by using a micrometer movement attached to the core of the extensometer LVDT. A shunt calibration value was established as 0.7882, and this shunt value was checked prior to testing. Sensitivity of the extensometer analog output is 5 volts/inch displacement.

Tension E Measurement

The extensometer and load cell analog outputs were used respectively to drive the x and y axes of a Hewlett Packard xy plotter. The x axis was calibrated to 0.2 volts/inch (0.04 inch LVDT displacement/inch), and the y axis was calibrated to 0.2 volts/inch (2000 pounds force/inch).

Tensile E is the ratio of tensile stress to tensile strain.

$$E = \text{stress}/\text{strain}$$

where

$$\text{stress} = \text{tensile force}/A \qquad (A \text{ is cross-section area})$$

$$= \text{tensile force}/5.25\ \text{in}^2 \qquad (\text{for } 2 \times 4 \text{ lumber})$$

$$\text{strain} = \text{elongation}/\text{extensometer gauge length}$$

For this test the extensometer gauge length is 127.5 inch; therefore:

$$E = (127.5/5.25)(\text{tensile force/elongation})$$

$$= (127.5/5.25)(2000y/0.04x)$$

$$= 1{,}214{,}000(y/x) \text{ psi}$$

The procedure is to measure the slope of the plot and multiply by 1.214 x 10^6 to get tensile E in psi.

To avoid breaking lumber while measuring tensile E, a force threshold of 10,000 pounds was set. In the automatic sequencing mode used for measuring tensile E, hydraulic pressure is increased until the force reaches 10,000 pounds. Then, the system automatically dumps oil pressure and the clamps release.

To avoid slippage in the grips, no tension force is applied until the clamp pressure is sufficiently high. Then the hydraulic oil is directed also to apply tensile force. This hydraulic sequencing operation causes tensile force to rise quickly during the start of the tension cycle. For a time during the start of the plot, the plotter is unable to keep up with this sudden increase in force; consequently, near the plot's origin, the plotted information is not useable. There is, however, an ample length of straight line on the plot from which slope can be determined. An error analysis similar to that for bending E can be used to estimate error resulting from reading values from the plot in the computation of tensile E.

Tensile Strength

Following tensile E measurement, the extensometer is removed, the tester is switched to manual mode and force is increased until the piece ruptures. The highest force value achieved is held by the system and read from the digital panel meter if the meter function switch is turned to "peak".

Loading Rate

The hydraulic power supply consists of a two stage pump which supplies oil quickly at low pressure but slowly at pressures of importance during the tensioning part of tension testing. Figure 2 is a copy of the OTC flow versus pressure specifications for the PQ 120 series pump used with the system. At 2000 psi pressure (about 20,000 pounds force), oil flow is 150 in^3/min. If all of this oil were going into the tension cylinders (2 each with area 5.15 in^2), they would extend at 14.6 in/min. In turn if the lumber were stretching at this rate, it would fail in 2 to 3 seconds. In fact, failure occurred in 10 to 15 seconds. This is due to some of the oil going into the clamp cylinders, compliance in the soft grips and other parts of the clamps and machine frame, and perhaps to internal leakage in the hydraulic pump.

APPENDIX C

FORINTEK KNOT AND FAILURE CODE

TABLE C-1 - DESCRIPTION OF FAILURES FOR DIMENSION LUMBER

CODE	CAUSE OF FAILURE	CODE	DETAILS OF CAUSE OF FAILURE
23	Knot cluster	00	% of x-section displaced
24	Slope of grain (wide face)	00	Actual slope
25	Grain deviation	00	% of x-section where deflection is greater than 1:4
26	Cross grain (narrow face)	00	Actual slope
27	Shake and checks	01	Not through and less than 2' long
		02	Not through and more than 2' long
		03	Through and less than 2' average
		04	Through and more than 2' average
		05	Shake breaks less than 2/3 the edge
		06	Shake breaks more than 2/3 the edge
28	Splits	00	Average length of both sides
31	Unsound wood	01	White specks
		02	Honeycomb
		03	Brown rot
32	Pinworm holes		
33	Grub holes		
34	Teredo holes		
35	Bark pockets		
36	Pitch pocket		
37	Wane	01	#1 wane
		02	#2 wane
		03	#3 wane
42	Compression wood	00	% of x-section
43	Burl	00	% of x-section
45	Machine damage	01	Saw cut through edge
		02	All other saw cuts
		03	Mechanical damage at edge
		04	All other mechanical damage
46	Falling breaks		
47	Breaks		
48	Deviated pith	00	Actual slope
50	Longitudinal shear		
51	Compression		
52	Tension and compression		
53	Tension		
54	Lateral buckling		
55	Brash		
58	Knot		
59	Rate of growth		
60	Clear wood or small defects		

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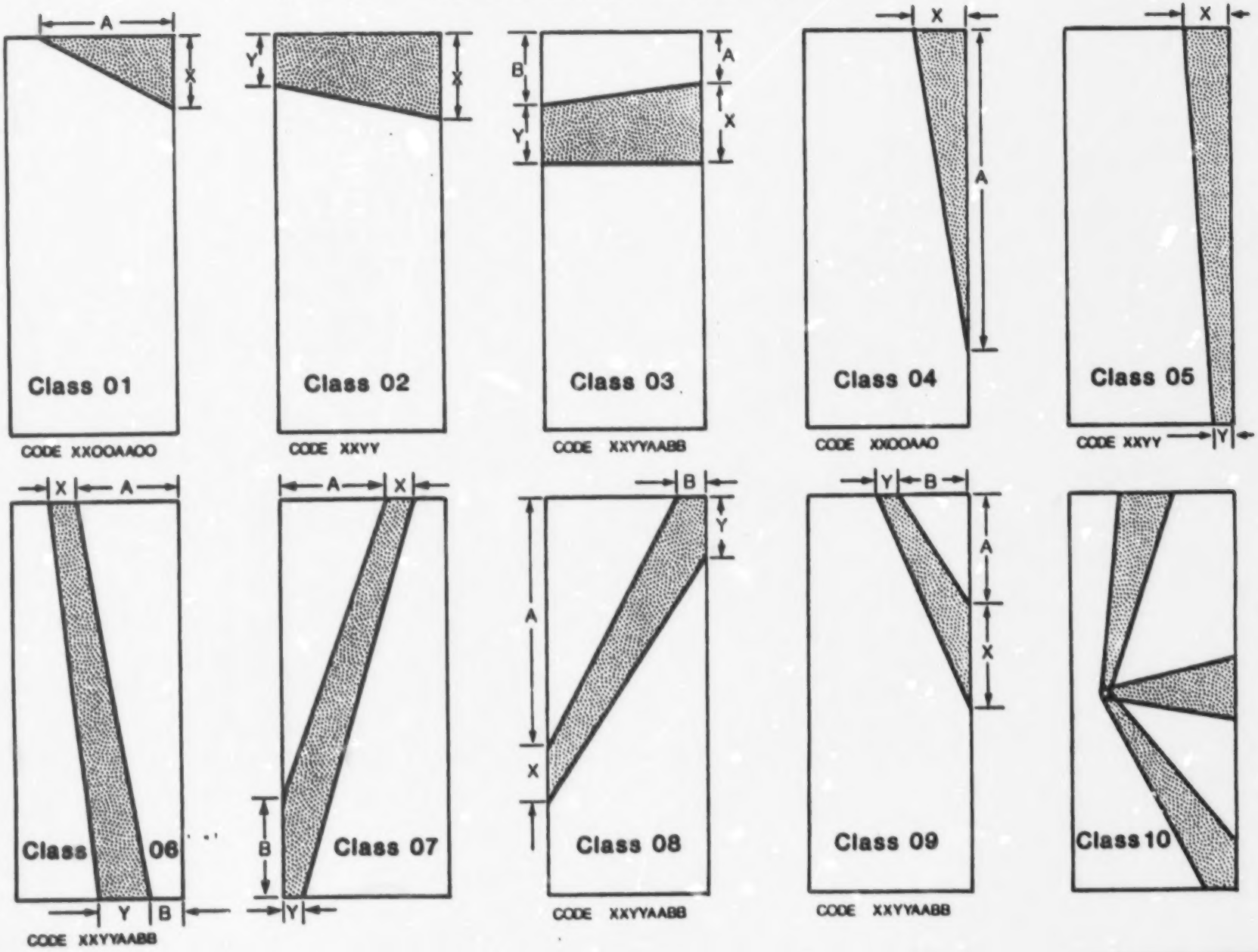
(REVISED Nov., 1983)

The codes for all failures other than knots are listed in Table 1 (Description of Failures for Dimension Lumber). These failures are defined and measured in accordance with, NLGA STANDARD GRADING RULES FOR CANADIAN LUMBER, with the following additions or changes:

1. Slope of grain - The slope of grain as measured on the wide face
2. Cross grain - The slope of grain as measured on the narrow face
3. Grain deviation - A localized grain deflection usually attributed to a large knot which itself is not present in the specimen
4. Deviated pith - The result of a sudden change of angle of the pith relative to the long axis of the piece.

For a description of failures not associated with a defect, i.e., longitudinal shear, compression, tension and brash failures refer to ASTM D143, Figure 8, diagrams c through f.

Figure C-1 - **WOOD ENGINEERING KNOT CODE**



The Forintek knot and failure coding system was developed to provide a rationale basis for analysing and characterizing the cause of failure in dimension lumber which has been tested to destruction.

The code provides a system which describes and measures the biological characteristics as well as the manufacturing and seasoning defects.

The system allows knots to be coded numerically with respect to size, orientation and location in the member cross-section using a minimum of measurements. All possible knot configurations have been incorporated into 10 knot "CLASSES" (shown in Figure C-1).

For knot classes, 1 through 9, the first digit designates the knot location on either the tension (0) or the compression (1) edge for bending tests. The second digit designates the knot class (1-9). The next 4 to 8 digits are used for the required knot measurements shown in Figure C-1.

Lumber containing a boxed pith (designated as Class 10) may be dealt with using one of 3 methods.

1. Code as a CLASS 10 knot and determine the percent displacement of the knot(s) by using the lumber grading displacement measuring technique. The knot is, however, not reproducable.

2. "Project" the pith to the surface and treat as one of the other 9 classes. This leads to a distortion of the geometry of the knot.

3. Measure knot as shown in Figure 3 (CLASS 10 supplementary). Measuring to the pith location is often difficult and an extra measurement (2 digits) is required.

Knots may be measured in either millimeters or 1/16th's, or 1/8th's of an inch. Millimeters are not recommended for larger lumber sizes (2x8's, 2x10's) as some measurements require over 99 mm's and a 3 digit number is not permitted in the code. Sixteenths of an inch are generally used since eigths of an inch may be too coarse for most purposes.

APPENDIX D

RESULTS OF ANALYSIS OF TENSION STRENGTH TESTS

To establish visual override rules, four parameters were determined for each failure caused by knots. For Tables D-1 to D-7, the following definitions apply:

Knot Displ. - percentage of specified cross section area occupied by the knot.

Edge Displ. - percentage of narrow or wide face occupied by the knot.

Knot Diam. - average diameter of the knot measured perpendicular to the axis of the knot.

Clear Wood - average distance perimeter of knot is from the narrow or wide face.

Grade - Format: a b c (if code is missing, value is 0)
- a = Off-grade code: 0 = on-grade (NLGA); 1 = off-grade (NLGA); 2 = offgrade (new class 8 rule from Phase I); 3 = off-grade new class 10 rule from Phase I).
- b = Grade controlling defect did not cause failure = 0; Grade controlling defect caused failure = 1.
- c = Defect causing failure rejected by new visual requirements = 1; defect causing failure not rejected by new visual requirements = 0.

The definitions used for each knot are given in Figures D-1 to D-6.

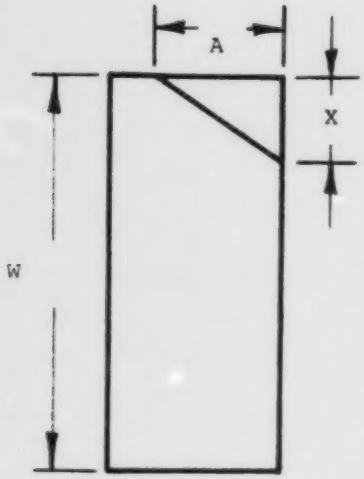


Figure D-1. Class 1 Knot

Edge displ. = A/T
Diameter = X $\cos(\tan^{-1}(X/A))$
Clear wood = 0.0

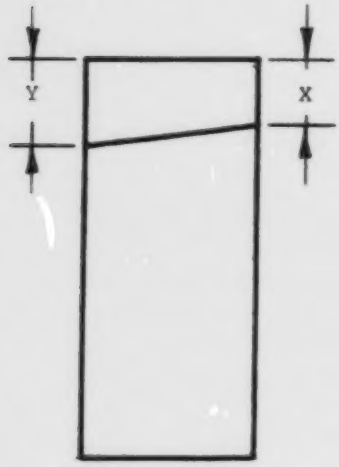


Figure D-2. Class 2 Knot

Edge displ. = 100.0
Diameter = (X + Y)/2
Clear wood = 0

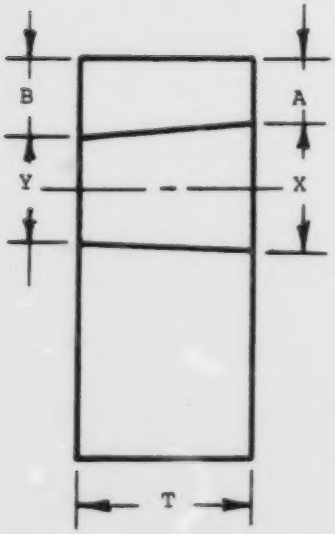


Figure D-3. Class 3 Knot

Edge displ. = 0.0
Diameter = (X + Y)/2
Clear wood = (A + B)/2

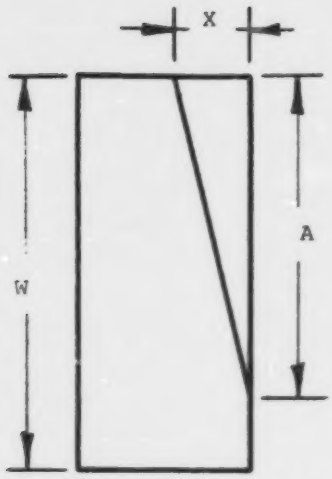


Figure D-4. Class 4 Knot

Edge displ. = A/W
Diameter = X $\cos(\tan^{-1}(X/A))$
Clear wood = 0.0

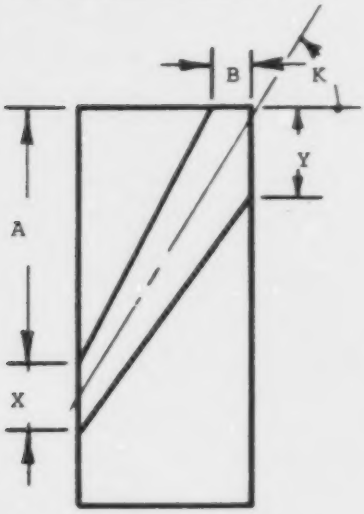


Figure D-5. Class 8 Knot

Edge displ. = B/T
Diameter = ((Y + BA/T) + X) cos (K)/S

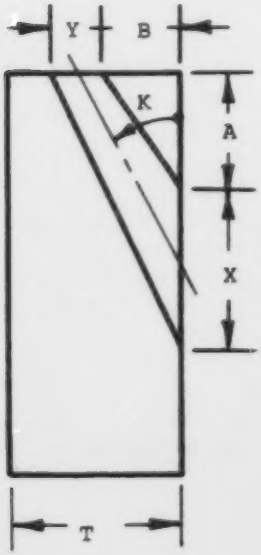


Figure D-6. Class 9 Knot

Edge displ. = Y/T
Diameter = (X + Y)sin(K)/2
Clear wood = A B/(2T)

Table D-1 - Class 1 Knot

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
2	305	14.8	9.1	92.11	0.63	0.00	0
1	8	14.9	9.0	89.47	0.63	0.00	0
----------	Specified 5th percentile load (17.3 kips)						----------
3	20	19.4	9.8	73.68	0.72	0.00	0
1	26	19.7	10.1	39.47	0.56	0.00	0
2	31	19.8	9.4	84.21	0.67	0.00	0
4	344	20.6	13.0	86.84	0.82	0.00	0
4	232	21.2	10.3	92.11	0.68	0.00	0
3	291	22.9	14.4	86.84	0.87	0.00	0
3	13	23.3	5.4	86.84	0.41	0.00	0
2	2	23.5	8.8	78.95	0.66	0.00	0
4	264	23.9	6.4	55.26	0.58	0.00	0
2	67	24.2	9.5	78.95	0.70	0.00	0
4	347	24.5	9.5	81.58	0.68	0.00	0
4	327	24.7	5.5	65.79	0.51	0.00	0
2	352	25.7	9.4	94.74	0.63	0.00	0
3	77	25.8	5.4	81.58	0.44	0.00	0
1	55	27.2	6.8	65.79	0.60	0.00	0
2	214	27.3	8.2	71.05	0.65	0.00	0
1	56	27.5	11.2	100.00	0.70	0.00	0
2	331	27.8	5.8	52.63	0.56	0.00	0
4	42	28.5	8.8	78.95	0.66	0.00	0
4	55	29.1	7.9	71.05	0.63	0.00	0
3	38	29.4	5.9	71.05	0.52	0.00	0
1	24	30.2	9.1	71.05	0.69	0.00	0
1	223	30.3	8.0	84.21	0.59	0.00	0
1	216	30.3	11.8	92.11	0.76	0.00	0
4	82	30.8	6.6	84.21	0.50	0.00	0
4	328	31.0	5.6	47.37	0.55	0.00	0
2	346	31.9	7.5	81.58	0.56	0.00	0
4	97	32.3	5.8	52.63	0.56	0.00	0
4	272	35.6	7.6	92.11	0.54	0.00	0
4	67	36.2	5.2	78.95	0.44	0.00	0
3	258	36.8	5.5	65.79	0.51	0.00	0
1	271	38.0	4.8	57.89	0.49	0.00	0
1	79	39.5	5.5	84.21	0.44	0.00	0
3	261	40.0	3.8	52.63	0.43	0.00	0

Phase I		Phase II		
18	+	18	=	36 (Total)
1	+	1	=	2 (Total below 17.3 kips)
1	+	1	=	2 (Final total below 17.3 kips)

Table D-2 - Class 2 Knot

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
3	103	5.8	45.0	100.00	1.59	0.00	1 1
4	252	14.1	30.3	100.00	1.08	0.00	1 1
2	315	16.2	19.4	100.00	0.69	0.00	1 1
3	264	16.9	16.4	100.00	0.59	0.00	0
4	205	16.9	21.9	100.00	0.79	0.00	1 1
----------	Specified 5th percentile load (17.3 kips)						----------
2	216	18.0	16.5	100.00	0.59	0.00	0
2	102	18.5	21.0	100.00	0.75	0.00	1 1
4	88	18.8	11.8	100.00	0.41	0.00	0
2	252	19.0	11.4	100.00	0.41	0.00	0
1	101	19.1	8.8	100.00	0.31	0.00	1
2	254	19.1	16.8	100.00	0.59	0.00	0
4	68	19.1	18.9	100.00	0.67	0.00	0
2	293	19.4	12.6	100.00	0.45	0.00	0
3	14	19.7	14.3	100.00	0.51	0.00	0
3	243	20.0	17.2	100.00	0.61	0.00	1 1
1	284	20.3	15.1	100.00	0.55	0.00	0
1	242	20.5	20.6	100.00	0.73	0.00	1 1
4	349	20.8	13.8	100.00	0.49	0.00	0
2	336	21.3	15.5	100.00	0.55	0.00	0
2	288	21.5	13.9	100.00	0.49	0.00	0
2	22	21.8	14.7	100.00	0.51	0.00	0
2	14	22.1	10.1	100.00	0.35	0.00	0
4	41	22.4	18.1	100.00	0.65	0.00	0
1	346	22.5	16.8	100.00	0.59	0.00	1 1
2	88	22.6	16.8	100.00	0.59	0.00	0
4	316	22.7	15.6	100.00	0.55	0.00	0
2	253	22.9	10.9	100.00	0.39	0.00	0
1	380	22.9	15.5	100.00	0.55	0.00	0
2	103	22.9	18.1	100.00	0.65	0.00	1
3	314	23.1	18.1	100.00	0.65	0.00	1 1
4	92	23.5	16.8	100.00	0.59	0.00	0
2	246	23.7	22.3	100.00	0.79	0.00	1 1
3	307	24.3	16.8	100.00	0.59	0.00	1
2	276	24.8	12.9	100.00	0.47	0.00	0
3	346	25.4	12.6	100.00	0.45	0.00	0
2	1	25.6	7.1	100.00	0.26	0.00	0
2	95	25.9	8.0	100.00	0.28	0.00	0
2	338	26.0	20.6	100.00	0.73	0.00	1 1
4	291	26.2	13.9	100.00	0.49	0.00	0
2	201	27.0	7.6	100.00	0.28	0.00	0
4	28	27.2	13.9	100.00	0.49	0.00	0
4	230	27.2	22.7	100.00	0.81	0.00	1 1

Table D-2 - Class 2 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
4	30	27.3	9.2	100.00	0.31	0.00	0
3	311	27.4	22.7	100.00	0.81	0.00	1 1
1	287	27.6	10.5	100.00	0.37	0.00	0
2	68	27.6	16.0	100.00	0.57	0.00	0
2	342	28.5	10.9	100.00	0.39	0.00	0
2	292	29.7	12.2	100.00	0.43	0.00	0
4	215	30.2	12.2	100.00	0.43	0.00	0
4	302	31.4	8.4	100.00	0.30	0.00	0
3	266	32.9	12.2	100.00	0.43	0.00	0
4	251	33.2	11.8	100.00	0.41	0.00	0
3	59	37.5	8.8	100.00	0.31	0.00	0

Phase I		Phase II		
18	+	35	= 53	(Total)
1	+	4	= 5	(Total below 17.3 kips)
0	+	1	= 1	(Final total below 17.3 kips)

Table D-3 - Class 3 Knot

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
1	340	11.0	28.2	0.00	0.96	0.53	1 0 1
4	207	12.6	22.2	0.00	0.75	0.28	0 0 1
1	62	13.7	23.5	0.00	0.79	1.00	0 0 1
1	335	14.7	17.2	0.00	0.57	0.83	0
1	289	14.9	21.0	0.00	0.71	0.30	0 0 1
2	245	15.9	23.2	0.00	0.79	0.45	0 0 1
4	225	16.2	23.6	0.00	0.79	0.63	0 0 1
4	101	16.2	26.1	0.00	0.89	0.33	1 0 1
1	78	16.3	22.7	0.00	0.77	0.81	0 0 1
1	219	16.3	23.1	0.00	0.79	0.35	1 0 1
2	300	16.4	20.6	0.00	0.69	0.18	0
4	98	16.4	23.1	0.00	0.79	0.61	0 0 1
----------	Specified 5th percentile load (17.3 kips)						----------
1	91	17.4	17.3	0.00	0.57	1.08	0
2	89	17.6	23.6	0.00	0.79	0.39	0 0 1
1	209	17.7	23.6	0.00	0.79	0.73	1 0 1
1	1	18.1	27.3	0.00	0.93	0.67	0 0 1
1	268	18.8	21.0	0.00	0.71	1.38	1
4	289	18.9	23.6	0.00	0.79	0.22	0 0 1
2	297	19.4	20.6	0.00	0.69	0.47	0
2	255	19.9	14.7	0.00	0.47	1.20	0
3	250	20.0	11.8	0.00	0.37	1.38	0
2	38	20.0	21.9	0.00	0.75	0.55	0 0 1
2	219	20.2	21.0	0.00	0.71	0.81	0 0 1
2	77	20.2	24.4	0.00	0.83	0.22	0 0 1
2	302	20.4	16.8	0.00	0.55	1.59	0
3	337	20.4	16.8	0.00	0.55	1.67	1
3	5	20.7	24.4	0.00	0.83	0.24	0 0 1
2	208	21.7	24.4	0.00	0.83	0.63	0 0 1
4	46	22.3	21.0	0.00	0.71	0.37	0 0 1
2	98	22.4	19.8	0.00	0.65	1.32	0
2	80	22.5	9.7	0.00	0.30	0.51	0
4	290	22.7	22.7	0.00	0.77	0.98	0 0 1
1	293	22.8	27.8	0.00	0.94	1.04	0 0 1
2	8	23.0	14.7	0.00	0.47	0.77	0
2	62	23.0	26.1	0.00	0.89	0.65	0 0 1
3	306	23.2	18.5	0.00	0.61	0.41	0
4	73	23.4	14.7	0.00	0.47	0.93	0
4	86	23.5	20.7	0.00	0.69	0.24	0
2	18	23.6	12.6	0.00	0.39	1.22	0
3	63	23.6	17.2	0.00	0.57	0.18	0
4	105	23.7	24.4	0.00	0.83	0.91	1 0 1

Table D-3 - Class 3 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
4	298	23.9	22.3	0.00	0.75	0.57	2 0 1
4	94	24.1	20.6	0.00	0.69	1.28	0
4	60	24.5	14.3	0.00	0.45	1.28	0
1	86	24.6	29.0	0.00	0.98	0.67	0 0 1
1	300	24.7	34.5	0.00	1.18	1.00	0 0 1
3	235	24.9	14.7	0.00	0.47	1.32	0
4	66	25.0	15.1	0.00	0.49	1.34	0
4	292	25.1	27.4	0.00	0.93	0.43	0 0 1
4	351	25.2	12.6	0.00	0.39	0.51	0
2	217	25.5	17.1	0.00	0.57	0.28	0
4	336	25.6	17.2	0.00	0.57	1.20	0
1	342	25.9	20.6	0.00	0.69	1.18	0
4	342	26.0	20.7	0.00	0.69	0.75	0
1	204	26.3	18.9	0.00	0.67	0.00	0
1	60	26.3	24.0	0.00	0.81	0.49	0 0 1
1	65	26.7	6.3	0.00	0.18	1.	0
2	42	26.7	9.2	0.00	0.28	0.	0
3	96	26.8	21.0	0.00	0.71	1.32	0
2	272	26.9	16.0	0.00	0.53	1.14	0
2	35	26.9	20.2	0.00	0.67	1.42	0
4	77	26.9	28.2	0.00	0.96	0.81	0 0 1
3	78	27.0	19.8	0.00	0.65	1.32	0
2	261	27.3	10.5	0.00	0.33	0.81	0
2	69	27.4	11.8	0.00	0.37	0.98	0
3	279	27.5	17.6	0.00	0.59	1.22	0
1	98	27.7	13.1	0.00	0.41	1.63	0
1	201	27.9	12.5	0.00	0.41	1.46	0
1	57	28.1	13.5	0.00	0.43	0.73	0
2	322	28.1	16.0	0.00	0.53	0.96	0
1	95	28.2	9.3	0.00	0.28	1.14	0
3	215	28.3	12.6	0.00	0.39	1.12	0
1	377	28.4	22.3	0.00	0.75	0.67	0 0 1
3	352	28.6	18.5	0.00	0.61	1.26	0
2	344	28.8	12.2	0.00	0.39	1.54	0
4	11	28.9	15.1	0.00	0.49	1.02	0
3	4	29.2	13.5	0.00	0.43	0.55	0
2	54	29.2	13.9	0.00	0.45	1.28	0
4	307	29.3	17.7	0.00	0.59	1.63	0
1	231	29.4	11.3	0.00	0.35	1.38	0
2	251	29.4	19.4	0.00	0.63	1.04	0
3	338	29.5	10.1	0.00	0.31	0.81	0
4	224	29.7	21.5	0.00	0.71	0.47	0 0 1

Table D-3 - Class 3 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
3	37	29.8	17.7	0.00	0.59	0.87	0
2	350	30.1	17.2	0.00	0.57	0.93	0
4	254	30.3	15.6	0.00	0.51	1.24	0
2	96	30.9	10.1	0.00	0.31	1.02	0
2	241	30.9	15.6	0.00	0.51	1.10	0
2	37	30.9	16.8	0.00	0.55	0.39	0
4	283	31.0	22.6	0.00	0.77	1.30	0
2	56	31.1	8.4	0.00	0.26	0.39	0
1	18	31.3	15.1	0.00	0.49	1.61	0
4	90	31.3	23.1	0.00	0.79	0.59	0 0 1
2	75	31.5	10.5	0.00	0.33	1.24	0
4	1	31.5	19.8	0.00	0.65	1.10	0
2	24	31.9	10.1	0.00	0.31	1.57	0
1	338	32.0	11.4	0.00	0.35	0.14	0
2	324	32.3	7.6	0.00	0.24	1.40	0
2	271	32.8	14.3	0.00	0.45	1.34	0
3	290	33.1	25.6	0.00	0.87	0.73	0 0 1
2	296	33.5	18.5	0.00	0.61	1.34	0
4	308	33.6	10.9	0.00	0.33	1.36	0
2	229	33.6	19.0	0.00	0.63	0.51	0
1	92	33.9	16.8	0.00	0.55	1.12	0
2	25	34.1	8.9	0.00	0.28	1.63	0
4	237	34.2	13.0	0.00	0.41	1.22	0
3	74	34.3	11.5	0.00	0.35	1.14	0
1	331	34.9	11.8	0.00	0.37	0.65	0
4	332	34.9	13.5	0.00	0.43	0.73	0
3	9	35.0	19.4	0.00	0.63	0.83	0
4	265	35.3	11.8	0.00	0.37	0.57	0
2	48	35.6	20.6	0.00	0.69	1.08	0
4	223	35.7	10.5	0.00	0.33	0.30	0
4	346	35.8	23.2	0.00	0.79	0.49	0 0 1
4	282	35.9	20.7	0.00	0.69	1.22	0
3	11	36.7	17.0	0.00	0.57	0.45	0
3	211	37.2	7.1	0.00	0.22	0.35	0
1	53	37.7	13.5	0.00	0.43	1.06	0
2	281	38.0	9.7	0.00	0.30	0.69	0
4	54	38.6	26.6	0.00	0.91	1.34	0
2	19	39.0	6.6	0.00	0.20	0.85	0
4	5	40.0	13.8	0.00	0.45	0.31	0
4	274	40.3	21.0	0.00	0.71	0.51	0 0 1
4	353	40.4	16.4	0.00	0.53	1.12	0
3	201	40.9	15.2	0.00	0.49	0.67	0

Table D-3 - Class 3 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
4	79	41.1	12.6	0.00	0.39	1.20	0
4	21	42.9	14.3	0.00	0.47	1.18	0
4	83	45.5	13.4	0.00	0.43	1.52	0
4	80	46.2	10.1	0.00	0.31	1.14	0

Phase I		Phase II		
61	+	68	= 129	(Total)
1	+	4	= 5	(Total below 17.3 kips)
0	+	1	= 1	(Final total below 17.3 kips)

Table D-4 - Class 4 Knot

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
1	355	12.1	19.8	44.94	1.02	0.00	1 1
1	235	17.0	13.3	44.94	0.78	0.00	0
---------- Specified 5th percentile load (17.3 kips) ----------							
2	94	17.9	15.1	40.45	0.89	0.00	0
1	295	19.9	11.6	44.94	0.70	0.00	0
1	37	20.0	6.6	39.33	0.48	0.00	0
1	13	20.6	19.5	59.55	0.89	0.00	0
1	206	20.7	13.0	58.43	0.64	0.00	0
2	74	20.8	7.5	44.94	0.49	0.00	0
1	229	20.9	8.1	50.56	0.46	0.00	0
1	238	21.5	13.5	41.57	0.82	0.00	0
1	327	22.8	9.3	50.56	0.53	0.00	0
1	385	23.0	5.6	25.84	0.54	0.00	0
4	62	23.1	10.9	33.71	0.76	0.00	0
3	60	23.2	10.5	47.19	0.62	0.00	0
3	26	24.5	6.6	50.56	0.38	0.00	0
2	222	24.5	13.1	33.71	0.84	0.00	0
4	19	24.8	9.6	33.71	0.70	0.00	0
1	77	24.9	7.4	39.33	0.51	0.00	0
3	202	25.1	6.1	73.03	0.24	0.00	0
3	329	25.4	7.0	30.34	0.59	0.00	0
2	325	25.8	2.7	39.33	0.19	0.00	0
3	75	26.2	12.3	67.42	0.54	0.00	0
4	203	26.4	8.5	25.84	0.67	0.00	0
2	72	26.5	3.3	39.33	0.23	0.00	0
4	48	26.7	9.5	48.31	0.56	0.00	0
4	304	27.7	8.5	50.56	0.49	0.00	0
4	85	27.7	12.0	50.56	0.66	0.00	0
4	339	27.8	14.5	56.18	0.73	0.00	0
2	341	28.0	7.8	39.33	0.54	0.00	0
3	204	30.2	4.6	67.42	0.20	0.00	0
1	315	30.3	8.5	24.72	0.67	0.00	0
4	258	31.5	4.8	44.94	0.31	0.00	0
4	23	31.6	9.4	47.19	0.56	0.00	0
1	45	31.7	8.6	33.71	0.66	0.00	0
3	224	32.0	11.6	44.94	0.70	0.00	0
4	303	32.6	4.2	61.80	0.20	0.00	0
4	10	32.7	8.5	78.65	0.31	0.00	0
1	270	33.2	7.1	28.09	0.61	0.00	0
4	214	34.2	8.2	44.94	0.52	0.00	0
1	387	34.4	5.8	22.47	0.56	0.00	0
1	264	34.6	6.6	25.84	0.59	0.00	0

Table D-4 - Class 4 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
3	344	35.4	6.6	33.71	0.53	0.00	0
4	38	36.9	14.5	56.18	0.73	0.00	0
4	244	37.0	4.5	23.60	0.48	0.00	0
3	213	37.2	5.4	28.09	0.51	0.00	0
3	285	37.2	8.9	44.94	0.55	0.00	0
4	310	37.4	3.5	22.47	0.41	0.00	0
1	46	44.0	4.9	24.72	0.51	0.00	0

Phase I		Phase II		
18	+	30	=	48 (Total)
0	+	2	=	2 (Total below 17.3 kips)
0	+	1	=	1 (Final total below 17.3 kips)

Table D-5 - Class 8 Knot

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
2	298	9.3	29.0	26.32	0.91	0.09	1 0 1
2	318	11.1	23.3	65.79	0.72	0.06	1 1 1
1	232	12.6	19.4	52.63	0.43	0.42	3
1	27	13.0	15.9	57.89	0.37	0.31	0
1	322	13.3	28.4	78.95	0.82	0.03	1 1 1
1	75	13.8	20.5	36.84	0.60	0.24	0
2	91	14.1	22.9	31.58	0.67	0.24	0 0 1
2	87	14.5	25.5	13.16	0.70	0.43	0 0 1
2	218	14.5	30.9	47.37	0.86	0.19	1 0 1
1	363	14.7	23.7	13.16	0.70	0.29	0 0 1
4	216	14.7	26.5	60.53	0.80	0.08	1 1 1
4	280	15.2	20.9	57.89	0.61	0.15	0
4	297	15.3	18.3	65.79	0.58	0.06	1 1
1	303	15.3	28.3	42.11	0.78	0.25	0 0 1
2	66	15.4	18.2	23.68	0.56	0.20	0
1	48	15.4	18.9	55.26	0.60	0.07	0
4	103	15.4	22.0	47.37	0.72	0.05	1 1 1
2	90	15.5	27.4	26.32	0.78	0.26	0 0 1
1	105	15.6	24.8	68.42	0.70	0.09	1 1 1
4	236	15.6	37.3	39.47	1.07	0.12	1 1 1
1	333	15.8	28.6	39.47	0.75	0.33	0 0 1
1	252	15.9	25.1	18.42	0.77	0.16	1 0 1
1	296	15.9	29.5	50.00	0.85	0.15	0 0 1
3	102	16.0	21.1	52.63	0.68	0.07	1 1 1
1	248	16.1	23.4	47.37	0.68	0.17	0 0 1
1	329	16.3	15.4	13.16	0.42	0.51	0
2	70	16.6	14.7	21.05	0.44	0.28	0
1	249	16.6	21.2	57.89	0.68	0.06	0 0 1
1	372	16.6	24.5	44.74	0.74	0.13	2 0 1
2	105	16.7	23.6	39.47	0.74	0.11	1 1 1
2	328	16.8	19.5	2.63	0.54	0.54	0
4	217	17.0	23.4	52.63	0.72	0.10	1 1 1
3	225	17.1	16.3	28.95	0.51	0.14	0
1	274	17.1	17.7	73.68	0.58	0.03	0
1	203	17.1	22.3	39.47	0.67	0.19	0 0 1
----------	Specified 5th percentile load (17.3 kips)						----------
4	284	17.4	23.9	52.63	0.78	0.03	1 1 1
2	257	17.6	26.7	73.68	0.77	0.05	1 1 1
2	85	17.8	23.7	21.05	0.77	0.[illegible]	0 0 1
2	40	18.1	16.8	18.42	0.51	0.19	0
1	288	18.1	19.9	39.47	0.61	0.18	0
2	314	18.1	20.8	65.79	0.68	0.04	1 1 1

Table D-5 - Class 8 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
1	382	18.2	12.7	52.63	0.36	0.23	3
2	223	18.4	17.3	39.47	0.51	0.24	0
4	259	18.5	15.1	39.47	0.48	0.12	1
2	267	18.5	24.3	55.26	0.66	0.19	1 1 1
4	262	18.5	27.0	60.53	0.81	0.08	1 1 1
1	96	18.9	25.6	52.63	0.74	0.16	0
4	72	19.0	16.9	18.42	0.53	0.14	0
3	56	19.3	17.4	26.32	0.56	0.12	0
1	208	19.7	14.1	23.68	0.38	0.50	0
4	238	19.9	20.9	47.37	0.68	0.07	1 1 1
2	294	20.1	18.8	52.63	0.60	0.07	1 1
1	230	20.1	21.7	34.21	0.68	0.12	2 0 1
1	72	20.2	12.9	44.74	0.31	0.46	0
3	212	20.2	23.5	52.63	0.66	0.19	0 0 1
1	258	20.2	23.8	2.63	0.62	0.61	0
3	316	20.3	23.5	26.32	0.68	0.29	1 0 1
1	207	20.4	24.9	36.84	0.72	0.22	0 0 1
1	250	20.6	17.3	31.58	0.53	0.20	0
3	262	20.6	22.6	39.47	0.72	0.10	1 1 1
4	104	20.6	22.8	31.58	0.73	0.08	1 1 1
3	218	20.7	19.0	28.95	0.54	0.31	0
2	21	20.7	20.2	52.63	0.64	0.08	0
2	104	20.8	25.1	26.32	0.80	0.07	1 1 1
1	257	21.0	15.1	26.32	0.48	0.17	1
2	212	21.0	16.7	47.37	0.53	0.09	0
4	17	21.0	26.7	7.89	0.71	0.49	0 0 1
3	300	21.2	19.7	57.89	0.61	0.08	1 1
1	90	21.4	15.3	28.95	0.43	0.39	0
1	281	21.4	20.2	26.32	0.63	0.17	1 1
2	26	21.4	20.3	60.53	0.63	0.08	0
3	331	21.5	18.4	47.37	0.57	0.13	0
1	47	21.7	18.3	57.89	0.59	0.06	0
1	378	21.8	18.0	18.42	0.55	0.24	0
2	329	21.9	26.1	26.32	0.81	0.13	0 0 1
3	321	22.0	36.2	36.84	0.90	0.35	0 0 1
4	7	22.2	18.1	2.63	0.55	0.21	0
1	265	22.4	15.6	26.32	0.47	0.26	0
4	269	22.5	20.8	21.05	0.59	0.36	0
2	291	22.6	24.5	57.89	0.71	0.12	2 0 1
4	56	22.6	25.7	50.00	0.75	0.15	0 0 1
4	14	22.7	14.7	44.74	0.43	0.24	0
2	61	22.8	18.2	39.47	0.56	0.13	0

Table D-5 - Class 8 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
4	329	23.0	29.0	92.11	0.46	0.02	0
2	319	23.1	20.8	60.53	0.63	0.10	0
2	351	23.1	26.5	18.42	0.70	0.47	1 0 1
1	14	23.1	26.7	65.79	0.79	0.07	0 0 1
1	21	23.3	18.5	18.42	0.54	0.32	0
4	229	23.4	16.5	18.42	0.51	0.21	2
4	326	23.4	24.7	52.63	0.74	0.13	2 0 1
4	107	23.5	23.5	73.68	0.71	0.05	1 1 1
4	218	23.6	16.3	68.42	0.51	0.06	1 1
2	4	23.6	23.7	18.42	0.75	0.08	0 0 1
3	226	23.8	9.6	39.47	0.30	0.12	0
1	227	23.8	22.5	5.26	0.67	0.28	0 0 1
4	247	24.1	15.5	52.63	0.48	0.13	0
4	102	24.1	15.7	23.68	0.45	0.35	1 1
2	323	24.1	16.8	26.32	0.52	0.22	0
4	305	24.1	18.0	68.42	0.56	0.06	0
2	52	24.2	16.6	52.63	0.54	0.05	0
1	10	24.6	16.3	55.26	0.51	0.13	0
1	379	24.8	16.2	26.32	0.51	0.15	0
3	99	24.8	17.5	18.42	0.55	0.16	0
4	221	24.9	19.4	44.74	0.48	0.40	0
4	321	25.1	8.4	34.21	0.28	0.09	0
2	27	25.2	12.6	10.53	0.38	0.32	0
3	295	25.2	16.4	65.79	0.54	0.03	1 1
4	9	25.5	19.1	65.79	0.60	0.06	0
1	364	25.5	20.6	23.68	0.59	0.33	0
2	268	25.5	20.7	52.63	0.63	0.14	0
2	242	25.6	12.3	52.63	0.39	0.11	0
1	247	25.6	24.4	21.05	0.71	0.28	1 0 1
4	81	25.7	18.5	39.47	0.55	0.21	0
2	50	25.8	15.5	42.11	0.47	0.17	0
2	10	25.9	15.7	13.16	0.44	0.48	0
4	334	26.0	20.5	57.89	0.63	0.08	1 1
4	276	26.1	13.5	68.42	0.45	0.02	0
3	242	26.2	14.2	44.74	0.45	0.08	0
3	57	26.4	13.6	23.68	0.33	0.68	0
2	34	27.0	13.9	68.42	0.46	0.04	0
4	204	27.1	13.0	7.89	0.41	0.22	0
1	308	27.1	13.8	47.37	0.44	0.13	0
4	266	27.1	26.1	39.47	0.77	0.19	0 0 1
2	224	27.2	13.7	26.32	0.42	0.15	0
1	80	27.2	27.7	31.58	0.74	0.35	0 0 1

Table D-5 - Class 8 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
4	263	27.3	23.8	39.47	0.70	0.20	0 0 1
1	317	27.9	13.1	39.47	0.41	0.18	0
1	214	27.9	14.8	47.37	0.48	0.11	0
3	277	28.3	15.6	57.89	0.51	0.07	0
2	93	28.6	18.5	47.37	0.54	0.21	0
3	33	28.9	15.0	7.89	0.42	0.54	0
4	228	28.9	16.8	44.74	0.52	0.15	0
4	287	28.9	22.7	21.05	0.72	0.11	0 0 1
2	283	29.0	9.3	5.26	0.24	0.75	0
2	234	29.2	19.5	57.89	0.59	0.12	0
1	11	29.3	17.2	47.37	0.53	0.13	0
4	281	29.3	19.0	57.89	0.58	0.11	0
1	88	29.8	19.7	44.74	0.59	0.20	0
4	323	29.9	10.1	26.32	0.33	0.13	0
3	69	30.4	19.6	60.53	0.53	0.19	0
2	45	30.7	15.0	60.53	0.49	0.05	0
1	341	31.0	18.1	18.42	0.56	0.19	1
4	201	31.3	11.8	15.79	0.34	0.35	0
4	300	31.4	17.6	73.68	0.55	0.05	0
4	40	31.5	11.4	15.79	0.33	0.45	0
4	315	31.7	18.1	28.95	0.55	0.22	0
4	65	31.7	24.7	57.89	0.75	0.08	0 0 1
3	308	32.2	14.4	57.89	0.45	0.12	0
1	35	32.6	10.7	21.05	0.33	0.19	0
3	301	32.6	12.3	18.42	0.37	0.35	0
2	228	32.7	9.7	18.42	0.20	1.00	0
4	29	33.0	12.5	10.53	0.35	0.56	0
1	370	33.1	15.7	39.47	0.48	0.18	0
4	306	33.1	18.5	39.47	0.54	0.24	0
4	220	35.3	13.2	15.79	0.40	0.17	0
4	53	36.4	12.0	44.74	0.39	0.10	0
2	244	38.2	15.3	47.37	0.50	0.08	0
4	31	43.4	12.1	44.74	0.40	0.08	0
4	246	45.7	17.0	42.11	0.55	0.08	0

Phase I		Phase II		
57	+	102	= 159	(Total)
12	+	23	= 35	(Total below 17.3 kips)
5	+	7	= 12	(Final total below 17.3 kips)

Table D-6 - Class 9 Knot

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
1	260	11.6	16.3	47.37	0.12	0.26	0 0 1
1	368	15.5	9.9	39.47	0.41	0.11	0
1	266	16.1	18.3	68.42	0.55	0.07	0 0 1
1	359	16.2	12.1	52.63	0.18	0.16	0
1	94	16.9	23.8	50.56	0.48	0.09	0 0 1
---------- Specified 5th percentile load (17.3 kips) ----------							
4	106	18.1	17.6	81.58	0.86	0.01	1 1 1
3	19	18.6	6.6	60.53	0.58	0.02	0
3	101	18.8	31.0	73.68	0.57	0.09	1 1 1
3	275	18.9	17.6	57.89	0.52	0.09	0 0 1
2	207	19.6	9.3	24.72	0.41	0.09	0
1	61	19.9	10.9	31.46	0.32	0.09	0
3	105	20.1	15.1	68.42	0.63	0.09	1 0 1
1	73	20.3	7.8	36.84	0.21	0.18	0
1	309	20.3	22.9	44.74	0.10	0.62	3 0 1
1	29	20.4	14.1	44.74	0.44	0.09	0
4	37	20.8	9.8	21.05	0.07	0.84	0
2	20	20.8	16.8	76.32	0.74	0.04	0 0 1
3	239	21.0	9.5	39.47	0.49	0.09	0
3	104	21.1	18.9	63.16	0.46	0.13	1 1 1
2	354	21.6	8.9	26.32	0.30	0.26	0
1	339	21.7	10.3	44.74	0.37	0.17	0
1	348	21.7	11.5	39.47	0.14	0.37	0
1	276	21.8	12.9	31.58	0.34	0.10	0
4	59	22.0	13.3	44.74	0.46	0.15	0
1	100	22.0	17.0	47.37	0.46	0.05	0
2	220	22.1	9.1	34.21	0.37	0.10	0
1	89	22.8	14.9	65.79	0.65	0.06	0
3	91	23.6	9.8	52.63	0.48	0.03	0
3	6	23.8	13.5	52.63	0.57	0.05	0
4	340	24.0	14.3	44.74	0.48	0.20	0
2	47	24.2	12.4	60.53	0.61	0.05	0
2	312	24.9	6.8	52.63	0.51	0.04	0
3	48	24.9	13.7	57.89	0.61	0.04	0
3	223	25.4	8.1	23.68	0.03	0.10	0
1	82	25.5	14.5	73.68	0.80	0.03	0
2	345	26.1	10.8	36.84	0.43	0.15	1
3	310	26.3	11.5	39.47	0.44	0.12	0
4	71	26.4	14.0	52.63	0.61	0.09	0
3	305	26.6	9.7	39.47	0.45	0.11	0
2	9	26.7	11.9	52.63	0.56	0.11	0
1	239	26.8	10.7	39.47	0.24	0.35	0
2	227	26.9	17.6	47.37	0.43	0.13	0

Table D-6 - Class 9 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
3	240	27.0	6.7	34.21	0.16	0.25	0
4	333	27.2	6.2	36.84	0.44	0.03	0
3	241	27.5	7.9	52.63	0.52	0.03	0
2	284	27.5	11.3	39.47	0.43	0.21	0
4	222	27.7	15.7	73.68	0.71	0.04	0 0 1
1	314	27.9	8.5	44.74	0.46	0.05	0
3	209	27.9	11.3	42.11	0.49	0.13	0
2	347	28.6	14.0	36.84	0.32	0.12	0
4	343	28.8	9.6	60.53	0.58	0.02	0
2	29	28.8	13.2	50.00	0.40	0.10	0
1	351	28.9	12.5	44.74	0.28	0.20	0
3	31	29.2	12.7	42.11	0.47	0.14	0
1	49	29.5	8.0	26.32	0.26	0.12	0
4	250	29.7	10.0	39.47	0.46	0.12	0
3	73	29.8	8.7	52.63	0.55	0.06	0
4	337	29.8	9.8	57.89	0.61	0.04	0
3	7	30.4	13.6	36.84	0.36	0.07	0
1	17	30.8	7.9	57.89	0.58	0.02	0
1	365	30.8	13.5	50.00	0.55	0.07	0
4	84	30.9	7.8	39.47	0.42	0.05	0
2	16	31.1	3.5	28.95	0.31	0.01	0
1	277	31.8	11.5	57.89	0.62	0.04	0
4	260	32.5	8.7	52.63	0.52	0.03	0
3	284	32.6	5.4	39.47	0.32	0.03	0
4	211	33.1	6.3	28.09	0.14	0.04	0
4	330	33.1	7.5	26.32	0.28	0.12	0
1	74	33.4	7.8	34.21	0.36	0.08	0
3	76	34.4	7.4	26.32	0.35	0.05	0
4	95	35.1	11.3	36.84	0.06	0.07	0
1	374	35.2	8.4	57.89	0.62	0.03	0
3	207	35.4	5.4	18.42	0.24	0.11	0
3	24	35.9	9.7	28.95	0.11	0.54	0
3	317	36.0	5.3	7.87	0.15	0.13	0
3	28	36.0	13.1	44.74	0.45	0.16	0
3	350	37.3	7.3	28.95	0.32	0.12	0
1	22	38.5	9.1	31.46	0.29	0.05	0
4	335	39.6	8.3	39.47	0.43	0.10	0
3	217	42.6	9.8	18.42	0.18	0.52	0

Phase I		Phase II		
35	+	45	= 80	(Total)
1	+	4	= 5	(Total below 17.3 kips)
0	+	2	= 2	(Final total below 17.3 kips)

Table D-7 - Class 10 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
3	280	25.4	10.0	0.00	0.00	0.00	0
3	333	25.5	16.0	0.00	0.00	0.00	0
2	36	25.9	5.0	0.00	0.00	0.00	0
2	97	25.9	10.0	0.00	0.00	0.00	0
1	40	25.9	12.0	0.00	0.00	0.00	0
1	305	25.9	32.0	0.00	0.00	0.00	3
1	373	26.2	5.0	0.00	0.00	0.00	0
3	41	26.2	10.0	0.00	0.00	0.00	0
1	324	26.4	15.0	0.00	0.00	0.00	0
2	250	26.5	7.0	0.00	0.00	0.00	0
3	47	26.5	10.0	0.00	0.00	0.00	0
1	33	26.5	13.0	0.00	0.00	0.00	0
3	98	26.5	17.0	0.00	0.00	0.00	0
3	297	26.5	38.0	0.00	0.00	0.00	0 0 1
2	213	26.6	7.0	0.00	0.00	0.00	0
3	236	26.6	12.0	0.00	0.00	0.00	0
1	311	26.6	13.0	0.00	0.00	0.00	0
3	94	26.6	15.0	0.00	0.00	0.00	0
3	336	26.7	10.0	0.00	0.00	0.00	0
1	369	26.7	12.0	0.00	0.00	0.00	0
1	318	26.7	21.0	0.00	0.00	0.00	0
3	348	26.8	10.0	0.00	0.00	0.00	0
2	295	26.8	28.0	0.00	0.00	0.00	0
4	322	27.0	7.0	0.00	0.00	0.00	0
1	12	27.0	15.0	0.00	0.00	0.00	0
1	282	27.0	25.0	0.00	0.00	0.00	0
3	244	27.2	10.0	0.00	0.00	0.00	0
1	236	27.3	10.0	0.00	0.00	0.00	0
3	322	27.4	17.0	0.00	0.00	0.00	0
1	344	27.5	10.0	0.00	0.00	0.00	0
3	315	27.6	7.0	0.00	0.00	0.00	0
1	23	27.7	10.0	0.00	0.00	0.00	0
2	64	27.8	25.0	0.00	0.00	0.00	0
2	316	27.9	10.0	0.00	0.00	0.00	0
3	3	28.2	9.0	0.00	0.00	0.00	0
1	58	28.2	15.0	0.00	0.00	0.00	0
3	274	28.4	7.0	0.00	0.00	0.00	0
1	297	28.4	12.0	0.00	0.00	0.00	0
4	24	28.5	15.0	0.00	0.00	0.00	0
1	254	28.5	25.0	0.00	0.00	0.00	3
3	263	28.6	7.0	0.00	0.00	0.00	0
3	228	28.7	7.0	0.00	0.00	0.00	0

Table D-7 - Class 10 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
3	32	22.2	28.0	0.00	0.00	0.00	0
1	350	22.3	19.0	0.00	0.00	0.00	0
2	17	22.4	10.0	0.00	0.00	0.00	0
1	298	22.4	10.0	0.00	0.00	0.00	0
1	290	22.5	31.0	0.00	0.00	0.00	0
1	356	22.6	19.0	0.00	0.00	0.00	0
3	354	22.7	12.0	0.00	0.00	0.00	0
3	253	22.7	24.0	0.00	0.00	0.00	0
3	100	22.8	15.0	0.00	0.00	0.00	0
1	81	22.9	15.0	0.00	0.00	0.00	0
4	8	22.9	15.0	0.00	0.00	0.00	0
2	221	23.0	10.0	0.00	0.00	0.00	0
4	301	23.0	23.0	0.00	0.00	0.00	0
2	57	23.1	19.0	0.00	0.00	0.00	0
2	243	23.3	12.0	0.00	0.00	0.00	0
3	283	23.3	18.0	0.00	0.00	0.00	0
3	86	23.5	18.0	0.00	0.00	0.00	0
2	99	23.6	19.0	0.00	0.00	0.00	0
1	304	23.6	24.0	0.00	0.00	0.00	0
2	301	23.6	31.0	0.00	0.00	0.00	0
1	291	23.7	10.0	0.00	0.00	0.00	0
3	92	23.7	22.0	0.00	0.00	0.00	0
1	256	23.8	15.0	0.00	0.00	0.00	3
2	266	23.8	23.0	0.00	0.00	0.00	1
3	323	23.9	12.0	0.00	0.00	0.00	0
1	267	23.9	25.0	0.00	0.00	0.00	3
4	296	24.0	31.0	0.00	0.00	0.00	0
1	224	24.1	14.0	0.00	0.00	0.00	0
3	237	24.5	10.0	0.00	0.00	0.00	0
1	2	24.5	20.0	0.00	0.00	0.00	0
3	95	24.6	10.0	0.00	0.00	0.00	0
1	71	24.6	18.0	0.00	0.00	0.00	0
3	238	24.7	14.0	0.00	0.00	0.00	0
2	84	24.7	15.0	0.00	0.00	0.00	0
1	19	24.9	20.0	0.00	0.00	0.00	0
1	330	24.9	21.0	0.00	0.00	0.00	0
2	5	25.0	10.0	0.00	0.00	0.00	0
1	42	25.0	22.0	0.00	0.00	0.00	0
3	17	25.2	10.0	0.00	0.00	0.00	0
4	20	25.2	22.0	0.00	0.00	0.00	0
1	273	25.2	28.0	0.00	0.00	0.00	0
2	236	25.3	10.0	0.00	0.00	0.00	0

Table D-7 - Class 10 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
1	6	19.1	25.0	0.00	0.00	0.00	0
1	354	19.2	21.0	0.00	0.00	0.00	0
1	349	19.2	23.0	0.00	0.00	0.00	0
1	69	19.3	13.0	0.00	0.00	0.00	0
1	263	19.3	21.0	0.00	0.00	0.00	0
1	320	19.4	27.0	0.00	0.00	0.00	0
1	343	19.5	17.0	0.00	0.00	0.00	0
2	304	19.5	30.0	0.00	0.00	0.00	0
1	279	19.7	12.0	0.00	0.00	0.00	0
1	376	19.7	24.0	0.00	0.00	0.00	0
1	262	19.7	27.0	0.00	0.00	0.00	0
1	36	19.7	31.0	0.00	0.00	0.00	0
1	210	19.9	25.0	0.00	0.00	0.00	3
1	384	20.1	34.0	0.00	0.00	0.00	0 0 1
1	240	20.2	25.0	0.00	0.00	0.00	0
1	15	20.2	36.0	0.00	0.00	0.00	0 0 1
1	362	20.4	10.0	0.00	0.00	0.00	0
1	44	20.5	10.0	0.00	0.00	0.00	0
1	345	20.5	14.0	0.00	0.00	0.00	0
1	375	20.6	18.0	0.00	0.00	0.00	0
1	226	20.6	28.0	0.00	0.00	0.00	0
1	381	20.7	18.0	0.00	0.00	0.00	0
1	217	20.8	31.0	0.00	0.00	0.00	0
1	388	20.9	10.0	0.00	0.00	0.00	0
1	255	20.9	16.0	0.00	0.00	0.00	0
1	97	21.0	9.0	0.00	0.00	0.00	0
3	249	21.1	5.0	0.00	0.00	0.00	0
1	205	21.1	30.0	0.00	0.00	0.00	3
1	316	21.1	34.0	0.00	0.00	0.00	1 1 1
1	292	21.3	17.0	0.00	0.00	0.00	0
4	50	21.3	23.0	0.00	0.00	0.00	0
1	326	21.4	17.0	0.00	0.00	0.00	0
3	288	21.4	22.0	0.00	0.00	0.00	0
1	353	21.4	23.0	0.00	0.00	0.00	0
1	386	21.4	27.0	0.00	0.00	0.00	3
1	337	21.5	10.0	0.00	0.00	0.00	0
1	76	21.5	25.0	0.00	0.00	0.00	0
1	246	21.7	17.0	0.00	0.00	0.00	0
3	299	21.7	38.0	0.00	0.00	0.00	1 1 1
2	278	21.9	22.0	0.00	0.00	0.00	0
1	39	22.2	10.0	0.00	0.00	0.00	0
2	269	22.2	25.0	0.00	0.00	0.00	0

Table D-7 - Class 10 Knot

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
1	280	10.9	33.0	0.00	0.00	0.00	0 0 1
1	307	11.1	40.0	0.00	0.00	0.00	0 0 1
1	20	11.5	35.0	0.00	0.00	0.00	0 0 1
1	241	11.7	36.0	0.00	0.00	0.00	0 0 1
1	215	11.8	43.0	0.00	0.00	0.00	1 1 1
2	101	12.1	45.0	0.00	0.00	0.00	1 1 1
1	212	12.3	21.0	0.00	0.00	0.00	0
1	251	13.5	34.0	0.00	0.00	0.00	0 0 1
1	104	14.0	31.0	0.00	0.00	0.00	1 1
1	283	14.1	27.0	0.00	0.00	0.00	0
1	16	14.3	30.0	0.00	0.00	0.00	0
1	3	14.4	20.0	0.00	0.00	0.00	0
1	222	14.7	26.0	0.00	0.00	0.00	0
2	270	14.9	27.0	0.00	0.00	0.00	0
1	220	15.2	38.0	0.00	0.00	0.00	0 0 1
1	357	15.9	30.0	0.00	0.00	0.00	0
1	93	16.1	25.0	0.00	0.00	0.00	0
1	51	16.2	35.0	0.00	0.00	0.00	0 0 1
1	99	16.4	15.0	0.00	0.00	0.00	0
1	325	16.4	20.0	0.00	0.00	0.00	0
3	347	16.8	24.0	0.00	0.00	0.00	0
2	83	16.9	35.0	0.00	0.00	0.00	0 0 1
1	334	17.1	10.0	0.00	0.00	0.00	0
1	243	17.1	10.0	0.00	0.00	0.00	1
1	253	17.1	20.0	0.00	0.00	0.00	0
1	63	17.2	40.0	0.00	0.00	0.00	0 0 1
----------	Specified 5th percentile load (17.3 kips)						----------
1	218	17.3	20.0	0.00	0.00	0.00	0
3	312	17.7	13.0	0.00	0.00	0.00	0
3	292	17.8	24.0	0.00	0.00	0.00	0
1	259	17.9	5.0	0.00	0.00	0.00	0
2	15	17.9	35.0	0.00	0.00	0.00	0 0 1
1	85	18.0	28.0	0.00	0.00	0.00	0
1	66	18.1	15.0	0.00	0.00	0.00	0
2	340	18.6	17.0	0.00	0.00	0.00	0
3	40	18.7	10.0	0.00	0.00	0.00	0
1	233	18.7	29.0	0.00	0.00	0.00	0
1	285	18.8	20.0	0.00	0.00	0.00	0
1	383	19.0	12.0	0.00	0.00	0.00	0
1	323	19.0	22.0	0.00	0.00	0.00	1
3	87	19.1	15.0	0.00	0.00	0.00	0
1	211	19.1	22.0	0.00	0.00	0.00	0

Table D-7 - Class 10 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
3	246	28.7	20.0	0.00	0.00	0.00	0
1	366	28.8	28.0	0.00	0.00	0.00	0
3	84	28.8	31.0	0.00	0.00	0.00	0
3	70	28.9	12.0	0.00	0.00	0.00	0
1	64	28.9	17.0	0.00	0.00	0.00	0
2	63	29.4	16.0	0.00	0.00	0.00	0
1	103	29.6	10.0	0.00	0.00	0.00	1
3	219	29.6	12.0	0.00	0.00	0.00	0
2	317	29.8	20.0	0.00	0.00	0.00	0
4	27	29.8	30.0	0.00	0.00	0.00	0
1	38	29.9	10.0	0.00	0.00	0.00	0
2	334	29.9	13.0	0.00	0.00	0.00	0
1	225	30.1	10.0	0.00	0.00	0.00	0
1	275	30.2	12.0	0.00	0.00	0.00	0
2	248	30.2	20.0	0.00	0.00	0.00	0
3	303	30.5	14.0	0.00	0.00	0.00	0
3	324	30.6	12.0	0.00	0.00	0.00	0
1	321	30.8	17.0	0.00	0.00	0.00	0
2	282	30.9	21.0	0.00	0.00	0.00	0
3	71	31.0	7.0	0.00	0.00	0.00	0
1	234	31.0	12.0	0.00	0.00	0.00	0
3	27	31.0	20.0	0.00	0.00	0.00	0
3	230	31.1	7.0	0.00	0.00	0.00	0
2	59	31.1	32.0	0.00	0.00	0.00	0
3	93	31.2	10.0	0.00	0.00	0.00	0
4	294	31.5	10.0	0.00	0.00	0.00	0
1	358	31.7	12.0	0.00	0.00	0.00	0
2	335	31.8	10.0	0.00	0.00	0.00	0
3	62	31.9	10.0	0.00	0.00	0.00	0
4	273	32.0	20.0	0.00	0.00	0.00	0
2	287	32.1	15.0	0.00	0.00	0.00	0
3	326	32.2	10.0	0.00	0.00	0.00	0
1	41	32.2	18.0	0.00	0.00	0.00	0
1	7	32.2	20.0	0.00	0.00	0.00	0
3	248	32.3	15.0	0.00	0.00	0.00	0
3	220	32.4	10.0	0.00	0.00	0.00	0
1	34	32.4	10.0	0.00	0.00	0.00	0
4	39	32.5	5.0	0.00	0.00	0.00	0
3	46	32.6	10.0	0.00	0.00	0.00	0
2	303	32.7	10.0	0.00	0.00	0.00	0
4	261	32.7	14.0	0.00	0.00	0.00	0
2	349	32.8	10.0	0.00	0.00	0.00	1

Table D-7 - Class 10 Knot - cont'd

Mill Number	Piece Number	Max. Load (kips)	Knot Displ. (%)	Edge Displ. (%)	Knot Diameter (in.)	Clear Wood (in.)	Grade
3	39	32.9	5.0	0.00	0.00	0.00	0
2	290	33.0	14.0	0.00	0.00	0.00	0
4	295	33.0	31.0	0.00	0.00	0.00	0
4	75	33.1	10.0	0.00	0.00	0.00	0
4	331	33.2	10.0	0.00	0.00	0.00	0
1	9	33.3	28.0	0.00	0.00	0.00	0
1	52	33.5	25.0	0.00	0.00	0.00	0
1	5	33.7	15.0	0.00	0.00	0.00	0
3	332	33.9	16.0	0.00	0.00	0.00	0
3	79	34.0	5.0	0.00	0.00	0.00	0
1	31	34.3	14.0	0.00	0.00	0.00	0
1	54	34.4	12.0	0.00	0.00	0.00	0
4	257	34.6	10.0	0.00	0.00	0.00	0
3	54	34.6	14.0	0.00	0.00	0.00	0
3	319	34.9	10.0	0.00	0.00	0.00	0
3	318	35.2	10.0	0.00	0.00	0.00	0
3	23	35.5	13.0	0.00	0.00	0.00	0
1	328	35.7	7.0	0.00	0.00	0.00	0
3	1	35.7	10.0	0.00	0.00	0.00	0
1	28	36.6	7.0	0.00	0.00	0.00	0
1	59	37.1	10.0	0.00	0.00	0.00	0
3	351	37.7	12.0	0.00	0.00	0.00	0
1	67	38.6	14.0	0.00	0.00	0.00	0
1	313	38.7	20.0	0.00	0.00	0.00	0
3	68	39.4	5.0	0.00	0.00	0.00	0
2	333	41.2	24.0	0.00	0.00	0.00	0
3	22	41.5	5.0	0.00	0.00	0.00	0
3	233	42.6	12.0	0.00	0.00	0.00	0
4	341	43.2	25.0	0.00	0.00	0.00	0

Phase I		Phase II	
89	+	149 = 238	(Total)
10	+	16 = 26	(Total below 17.3 kips)
4	+	10 = 14	(Final total below 17.3 kips)

APPENDIX E

RESULTS OF FAILURES DUE TO SLOPE OF GRAIN AND GRAIN DEVIATION

Table E-1 - Slope of Grain (wide face)

Mill Number	Piece Number	Max. Load (kips)	Slope of Grain*	Grade
4	213	8.7	15	0
4	36	9.9	11	0
3	276	13.1	10	0 0 1
1	102	15.0	14	1
2	43	15.2	08	0 0 1
3	229	15.5	15	0
2	206	16.0	09	0 0 1
2	355	17.0	10	0 0 1
2	12	17.2	09	0 0 1
-- Specified 5th percentile load (17.3 kips) --				
4	51	17.4	09	0 0 1
2	256	17.7	13	1
4	348	18.2	10	0 0 1
1	301	18.4	16	0
4	350	18.7	14	0
4	99	20.0	08	0 0 1
2	273	20.2	05	0 0 1
2	71	20.2	09	0 0 1
3	343	20.2	12	0
4	275	20.3	07	1 1 1
4	18	21.3	16	0
2	204	21.6	14	0
3	255	21.8	16	0
4	57	21.9	13	0
4	96	22.1	11	0
4	49	22.2	13	0
2	60	22.8	16	0
3	89	23.0	10	0 0 1
4	61	23.0	10	0 0 1
4	74	23.2	13	0
2	307	23.2	11	0
4	69	23.6	11	0
3	247	23.9	11	0
4	320	24.1	08	0 0 1
4	267	24.3	07	1 1 1
4	34	24.5	17	0
3	49	24.7	16	0

* Longitudinal distance per unit deviation from the longitudinal axis.

Table E-1 - Slope of Grain (wide face) - cont'd

Mill Number	Piece Number	Max. Load (kips)	Slope of Grain*	Grade
4	58	24.9	16	0
4	253	25.0	14	1
3	55	25.4	07	0 0 1
1	312	25.6	17	0
4	206	25.7	10	0 0 1
1	371	25.9	17	0
4	248	26.1	21	0
4	309	26.3	18	0
4	202	26.4	13	0
3	340	26.4	10	0 0 1
3	349	27.4	08	0 0 1
4	93	27.6	20	0
4	22	28.0	09	0 0 1
3	278	28.2	10	0 0 1
4	299	28.8	12	0
4	210	29.0	11	0
2	230	29.0	12	0
3	353	29.6	15	0
4	270	29.7	20	0
3	51	30.3	10	0 0 1
4	226	30.5	16	0
2	46	30.6	13	0
4	2	30.8	10	0 0 1
1	299	31.0	15	0
3	355	31.5	13	0
3	88	31.5	19	0
4	3	31.7	18	0
4	286	33.2	13	0
2	6	34.2	16	0
3	10	34.8	13	0
2	332	35.0	14	0
4	33	35.5	20	0
4	293	37.8	20	0
2	76	38.2	19	0
2	275	39.0	13	0

* Longitudinal distance per unit deviation from the longitudinal axis.

Table E-2 - Grain Deviation

Mill Number	Piece Number	Max. Load (kips)	Section Displ.* (%)	Grade
2	55	10.4	02	0
2	225	11.7	04	0
3	335	15.2	60	0
4	285	16.7	04	0
1	360	16.9	50	0
3	8	17.0	07	0
- Specified 5th percentile load (17.3 kips) -				
2	53	18.0	07	0
2	39	19.6	07	0
1	87	19.7	20	0
4	278	21.3	30	0
2	203	22.2	75	0
3	268	22.3	03	0
4	319	24.0	30	0
2	274	24.0	75	0
4	63	24.1	15	0
3	282	24.9	06	0
2	235	24.9	50	0
3	339	25.3	25	0
4	6	26.3	40	0
3	272	26.4	75	0
2	339	27.6	25	0
3	18	28.2	40	0
3	34	31.2	25	0
3	345	36.2	15	0
2	264	37.0	33	0

* As specified in Appendix B (Forintek Knot and Failure Coding)